IMPROVED METHODOLOGY FOR SIZING OF NAVAL ELECTRICAL POWER PLANTS
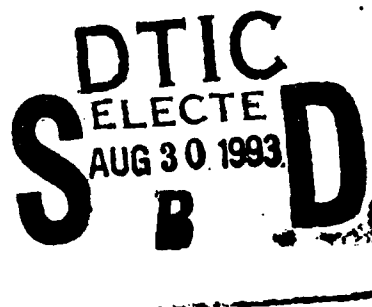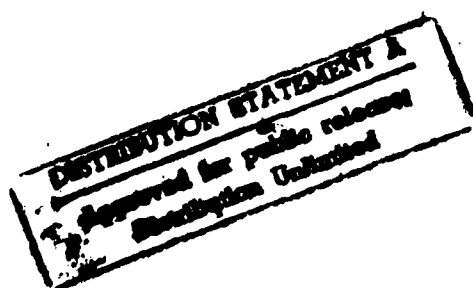
by

JAMES JEFFREY McGLOTHIN

Submitted to the Department of Ocean Engineering
on April 15, 1993, in partial fulfillment of the requirements
for the Degrees of Naval Engineer and Master of Science
in Electrical Engineering and Computer Science.

Abstract

Electrical power plants onboard ships of the United States Navy have traditionally been sized according to empirical methods. These methods have resulted in satisfactory plants but have not been updated to reflect recent improvements in equipment and analysis methods. Developing technologies under consideration for future ships, particularly integrated electric propulsion with propulsion derived ships service electrical power, will bring significantly different demands for electrical power. There is very little recent design experience to fall back on when designing a ship employing such technologies. In addition, current fiscal restraints demand that excess equipment and capacity be severely restricted in order to minimize procurement costs, manning, and maintenance costs. A methodology is proposed to evaluate candidate electric plant configurations (i.e. number and sizes of generating units) in terms of the probability that the required loads can be supplied. The alternatives can then be compared in terms of cost, weight, number of units, and total installed capacity to determine which is most cost effective. The methodology has been coded into a program which can be used to easily do the system comparisons. Several shipboard systems are analyzed to demonstrate the usefulness of the program.

Thesis Advisor: Dr. James L. Kirtley, Jr.
Title: Professor of Electrical Engineering and Computer Science

IMPROVED METHODOLOGY FOR SIZING OF NAVAL ELECTRICAL POWER PLANTS

by

JAMES JEFFREY McGLOTHIN

B.S. Electrical Engineering, University of Tennessee

(1982)

Submitted to the Department of

OCEAN ENGINEERING

and the Department of

ELECTRICAL ENGINEERING AND COMPUTER SCIENCE

in Partial Fulfillment of the

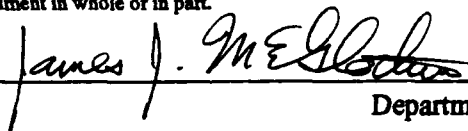Requirements for the Degrees of

NAVAL ENGINEER

and

MASTER OF SCIENCE IN ELECTRICAL ENGINEERING
AND COMPUTER SCIENCE

at the

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

MAY 1993

© James Jeffrey McGlothin 1993

Signature of Author _____

Department of Ocean Engineering
7 May 1993

Certified by _____
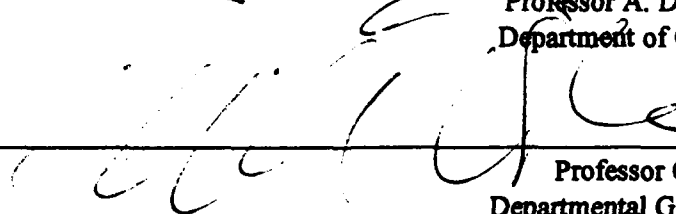
Professor James L. Kirtley, Jr.
Department of Electrical Engineering and Computer Science
Thesis Supervisor

Certified by _____

Professor A. Douglas Carmichael
Department of Ocean Engineering
Thesis Reader

Certified by _____

Professor Campbell L. Searle
Departmental Graduate Committee
Department of Electrical Engineering and Computer Science

Accepted by _____

Professor A. Douglas Carmichael
Departmental Graduate Committee
Department of Ocean Engineering

1

IMPROVED METHODOLOGY FOR SIZING OF NAVAL ELECTRICAL POWER PLANTS

by

JAMES JEFFREY McGLOTHIN

Abstract

Electrical power plants onboard ships of the United States Navy have traditionally been sized according to empirical methods. These methods have resu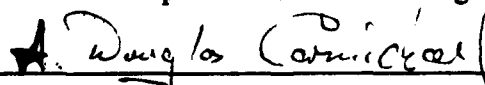lted in satisfactory plants but have not been updated to reflect recent improvements in equipment and analysis methods. Developing technologies under consideration for future ships, particularly integrated electric propulsion with propulsion derived ships service electrical power, will bring significantly different demands for electrical power. There is very little recent design experience to fall back on when designing a ship employing such technologies. In addition, current fiscal restraints demand that excess equipment and capacity be severely restricted in order to minimize procurement costs, manning, and maintenance costs. A methodology is proposed to evaluate candidate electric plant configurations (i.e. number and sizes of generating units) in terms of the probability that the required loads can be supplied. The alternatives can then be compared in terms of cost, weight, number of units, and total installed capacity to determine which is most cost effective. The methodology has been coded into a program which can be used to easily do the system comparisons. Several shipboard systems are analyzed to demonstrate the usefulness of the program.

Thesis Advisor: Dr. James L. Kirtley, Jr.
Title: Professor of Electrical Engineering and Computer Science

Acknowledgments

It would be impossible for me to thank everyone I would like to thank on this page. However, I will thank those I can without becoming too wordy, sentimental, or boring:

To the United States Navy, for giving me the opportunity to continue my education in a manner in which I certainly could not afford otherwise.

To Professors Kirtley and Carmichael, for allowing me to pursue a topic in which I was interested, for the help and guidance when it was necessary and the free rein when it wasn't.

To Captains Brooks and Brown and Commander Celotto, for reminding me on occasion that I am first and foremost a Naval Officer and should conduct all my affairs, including academic, as such.

To my mother and sister, who have shown me by example the true meaning of courage and persistence, and how to keep ones sense of humor in the worst of times. You are the bravest people I know.

To Ivy, Millie, and Curt, for their dedication to education, their unswerving loyalty and love, and their outstanding examples of how to live.

To Pop & Katie, for sticking together all these years. Happy 66th, and I hope the weather never breaks!

To my in-laws, Allen, Carole and Steve, who haven't been in-laws at all.

To Brenton, for your unconditional love and the periodic bursts of joy that always accompany your visits. Here's hoping you're as lucky in life as your Uncle JF, who loves you very much.

To those who have gone, Dad, Glen and Gracie, who counsel without speaking, listen without hearing, and guide without touching. I miss you.

To my wife Suzanne, for pestering, pushing and phoning; typing, touching and tugging; caring, cleaning and crying; shopping, sharing and shoveling; loving, living, and leaving me alone when I had to be; and being bored and lonely too much of the time. I couldn't have done it without you!

Most of all, to God, for through Him, all things are possible.

"Apply your heart to instruction and your ears to words of knowledge (Proverbs 23:12)."

3

Table of Contents

Chapter 1. Introduction

Some of the earliest decisions which must be made during the design of a Navy ship concern the propulsion plant. How many and what type of engines and transmissions are to be used and how much electrical generation capacity is needed must be decided early. These decisions have major consequences, for the propulsion plant is one of the heaviest and most voluminous components of a ship. Secondary effects, such as the amount of fuel which must be carried and the intake and exhaust volume required, are substantial. Tools are needed to help a designer evaluate candidate configurations early in the design process so that unnecessarily large plants are not selected. An oversize plant causes the entire ship to be larger, and thus more costly, than necessary. To date, Naval electrical plants have been designed which have operated satisfactorily. However, the existing design methodology is clearly defined only for ships that do not have integrated electric propulsion (propulsion power and ships electric power derived from separate systems). The Navy is currently working toward ships which make use of integrated electric drive technology (both propulsion power and ships electric power derived from the same source). However, there is currently no clearly defined methodology for determining the electrical generating capacity for such a ship. If the current methodology is used with the propulsion loads simply added in, the result could be an oversize, unnecessarily expensive plant.

Objective

The objective of this thesis is to develop a new method for sizing naval ship electric plants based on statistical reliability methods. Such a method would replace the empirical methods currently used, and allow designers to decide on the number and size of generators based on what would be considered an acceptable reliability level (or, alternately, an acceptable risk that power demands could not be met). The method would take into account whether the ship is electric drive and, if so, whether ships service power is propulsion derived or separately generated.

Background

Major changes are occurring in the nature of electrical systems onboard U.S. naval ships, both in the nature of the loads present and the generating equipment used. These changes include (but are not limited to):

- Power electronics and other solid state devices replacing machinery such as motor generator sets.

- Integrated electric drive propulsion (i.e. electrical power for propulsion and electrical power for other ship functions are derived from the same prime movers).

- Pulsed power weapons systems.

- Automated propulsion and ship service electric power system controls.

The above will have significant effects on the current ship design process. Among them:

- Propulsion shafting runs will be much shorter since the propeller will be driven by an electric motor rather than a turbine. This will allow much more flexibility in the locations of the major components of the engineering plant.

- Increased automation of systems will reduce the necessary manning. This will reduce the living space required and thereby make more room available for other functions (or reduce the ship size for the same capability).

- The demands on the electric power generating and distribution system will be much more complex.

The last change requires some explanation. Current ship designs have functionally separate systems for providing propulsion power and electrical power. While it is true that some electrical power is required for the propulsion plant (e.g. for electric powered seawater cooling pumps), the above statement is true from a conceptual standpoint. Electrical power is distributed throughout the ship and used for a variety of purposes, including combat systems, navigational systems, and "hotel" loads (cooking, heating and cooling, lighting, etc.). The demands on the electrical generating and distribution system are relatively simple. Most major variations in electric power demands are produced by the state of the combat system (whether or not weapons are being fired, which sensors are in operation, etc.) and not by the maneuvers (i.e. changes in speed and direction) of the ship. With the changes noted above come the added

demands of providing large amounts of power in short bursts for pulsed power weapons, as well as significant variations in electrical power demands with ship maneuvering. Since many missions require significant maneuvering (search and rescue, submarine hunting, etc.), the demands on the electrical system become much more complex and unpredictable.

In addition to the above, current fiscal conditions are forcing changes in ship design philosophy. No longer is capability the driving force. Cost has become the major player, and affordability the chief consideration when design decisions are made. This new design philosophy is forcing designers to reevaluate how much excess capacity should be installed on ships, since every extra component (or larger or more capable component) requires more space and weight, as well as more personnel to run, maintain and repair it. These effects add to the initial cost of the component itself. Therefore, a concerted effort must be made to minimize excess design margins and excess installed capacities.

Existing Analysis Tools

Naval electrical power plants differ greatly from the utility power grid [Refs 1, 2, and 3]. First, once a ship is built, the electric plant is virtually impossible to expand due to space and weight constraints. This is in contrast to the utilities, who can simply add generation facilities if current resources prove insufficient. Second, cable runs are short, limited basically to the length of the ship. This means that transmission line dynamics

are insignificant and the cable runs can be ignored in analyzing the behavior of the system. Third, since the components of the system are all located on the ship, they are in relatively close proximity. Information can be passed between them very rapidly. Fourth, because of cost, space, and weight constraints, the installed capacity and rotational inertia of the system generators are much smaller in magnitude when compared to the size of the loads than the commercial counterpart. This has two important consequences:

- The time constants of the prime movers are on the same order of magnitude as those of the major electrical loads. This makes time scale separation assumptions often made in commercial system analyses invalid. This is discussed in detail in Chapter 2 of Reference [1] and Chapter 2 of Reference [2].

- Since the electrical loads on a ship are relatively large and dynamically applied, the voltage and frequency excursions that can be produced are large compared to commercial systems. For example, Reference [4] allows the electrical frequency to vary plus or minus 3% from the nominal value, and the voltage to vary plus or minus 5% during normal conditions. Much larger variations (even system shutdown) are allowed for short periods during emergency conditions. Therefore, the "infinite bus" assumption often made in commercial system analyses is invalid.

The above factors make analysis of Naval shipboard electrical power systems quite difficult. The tools in general use by the commercial electric power industry are unsuitable for shipboard power system analysis due to the differences mentioned above

11

[Ref 1]. This, coupled with new developments in electric drive propulsion, etc., have led the Navy to begin developing its own analysis tools. Reference [1] details the first step in the development of an analysis tool called WAVESIM, suitable for the dynamic analysis of shipboard electric power systems. Reference [2] developed a stability analysis method compatible with WAVESIM. Reference [3] developed an analysis tool for assessment of the steady state generating and distribution capabilities of shipboard electric power systems with battle damage. These tools, when fully developed and proven for general Navy use, will allow the designer to simulate different conditions and choose between candidate electric plants (locations and types of generators, as well as control systems and distribution equipment) based on the simulated responses.

The Navy also uses analysis tools which are not specifically for electrical systems. The principle ship design tool used currently is called ASSET (Advanced Surface Ship Evaluation Tool). ASSET is a computer synthesis tool which allows a designer to construct a computer model of a ship and analyze the feasibility of the design, comparing it to current design practices and constraints and past designs. Reference [5] is the manual for TIGER, the Navy's reliability and availability analysis tool. TIGER calculates reliability and availability information using Monte Carlo methods.

The tools discussed above allow a relative assessment of the merits of alternative overall power plant designs. However, the initial decisions on how much generating capacity and the number of generators required onboard a ship are still based on

12

empirical methods which have not been updated to reflect current technological advances.

The current methodology does not provide the designer with a means for assessing the relative merits of candidate generator configurations during the early phases of design. That is, how many generators should be installed? How much benefit is actually obtained by installing an additional generator? Is a system consisting of several small generators really much more reliable than one consisting of fewer but larger generators? ASSET can be used for load estimation, but the question of generating system adequacy is not addressed from a reliability standpoint. TIGER could be used for some of these evaluations, but it has several important limitations:

- First, it is difficult to use. TIGER is a FORTRAN program which requires input in the form of text files. These files have complicated formats which require information on each component and operating rules for the system be placed in specific lines and columns in the file.

- Second, it evaluates systems based on operating rules (e.g. two of three subsystems must be operational for the system to be considered operational) and therefore is difficult to use to analyze systems made up of generators of different sizes.

- Third, the output consists of a text file for each run. Comparisons between configurations must then be made by extracting the pertinent information from each output file and comparing the data manually.

Once the number and sizes of generators are determined, the tools already developed could be employed. For example, the damage model [Ref 3] could be used to determine optimum locations for the generators and other electrical equipment from a survivability standpoint. WAVESIM [Ref 1] and the stability methods of Reference [2] could then be used to simulate the system to determine transient responses and overall system electrical stability for control purposes.

Program Development

The new methodology is coded as a personal computer (PC) based program called SMOKEY (since BEAVER was already taken, the author named the program after the mascot at the University of Tennessee where his undergraduate work was done. Smokey is the name of the blue tick hound dog that is the school mascot). The program is Windows based for ease of use. An installation program was also written to reduce startup time and ensure proper operation for inexperienced users.

The niche occupied by SMOKEY is as a preliminary design tool. SMOKEY allows the designer to evaluate several generator configurations in terms of availability. The selected configuration can then be evaluated in detail later in the ship design process when equipment locations, control system strategies, and distribution paths have been established using the tools previously mentioned.

The ability to compare configurations in terms of cost and weight early in the design process is the primary innovation of SMOKEY. The program allows a designer to easily evaluate the benefits of adding additional generators, enlarging generators, etc. based only on the anticipated loads. Since the loads can be estimated based on the mission of the ship and the weapons systems to be included, the electric generating plant can be decided on with a great degree of certainty very early in the design process. This is especially important in electric drive ships since the electric plant is the propulsion plant. Unnecessarily large plants mean larger and more expensive ships, which can no longer be tolerated.

Chapter 2. Electric System Sizing Concepts

Before beginning a description of the proposed improved methodology for sizing Naval electric power plants, it is appropriate to review some of the basic concepts of reliability analysis. In addition, this chapter will describe the basics of utility company reliability evaluation and sizing, and the current sizing methodology used during Naval ship design.

Reliability Concepts

The Standard Handbook for Electrical Engineers [Ref 6] defines the reliability of a power system as a measure of its "ability to serve all power demands made by all customers without failure over long periods of time." Availability is defined as the "percent of time that a unit is available to produce power whether needed by the system or not. It is a measure of overall unit reliability." Availability is easy to quantify. However, reliability is a harder concept to get a handle on. As stated in Reference [7]:

> It should be noted that the term reliability has a very wide
> range of meaning and cannot be associated with a single
> specific definition such as that often used in the
> mission-oriented sense. It is therefore necessary to
> recognize its extreme generality and to use it to indicate, in

a general rather than specific sense, the overall ability of

the system to perform its function.

Reference [7] goes on to state that reliability is made up of two basic aspects:

adequacy and security. Adequacy is basically having enough resources to supply the

load demand at any given time. Security relates to the systems ability to respond to

disturbances. Since this project focuses on sizing methods and not control systems, it is

the question of system adequacy that is dealt with in this thesis.

The basic parameter used in static capacity evaluation is the unit availability (the

probability of the unit being operational at a given time) or, alternately, unavailability

(the probability of the unit not being operational). These quantities are defined [Ref 8]

as follows:

$$AVAILABILITY = A = \frac{MTBF}{MTBF+MTTR}$$

and

$$UNAVAILABILITY = U = \frac{MTTR}{MTBF+MTTR} = 1-A$$

where   MTBF=Mean Time Between Failures

and   MTTR=Mean Time To Repair.

MTBF and MTTR are determined from actual failure and repair data for each

component. In a simple series system (i.e. a system in which each component must be

available for the system to be available), the availability of the system is the product of

the availabilities of the individual components. In a simple parallel system (i.e. a system

17

in which one component must be available for the system to be available), the availability of the system is 1 minus the product of the individual component unavailabilities. The proofs of these statements are straightforward, and so are not repeated here.

Utility Company Sizing Methods

Commercial power systems are most frequently analyzed by assigning generator units and loads to nodes interconnected by transmission lines (and transformers, circuit breakers, etc.). The transmission lines are modeled as single lines, and the sources and loads as providers and users of power (as opposed to voltages, currents, impedances, etc.). This is commonly called the power distribution "grid." Historical data is used to produce probabilistic models of the generators and loads. Availabilities for each generating unit are determined, then the probabilities that various generating capacities will be unavailable are combined to form the capacity outage probability table. The capacity outage probability table is simply an array of possible capacity levels (for example, in a system with two 1 kW generators, the possible capacities are 0, 1, and 2 kW) and the associated probabilities of existence. In the simple case where all units are the same capacity, the probabilities can be calculated using the binomial distribution [Ref 8]. When the system is comprised of generators with different capacities, a recursive technique, such as the one shown in Reference [9], is generally used to calculate the probabilities.

The capacity outage probability table is then combined [Ref 7] with the load model using probabilistic techniques to produce a system risk index. The most common load model is called the daily peak load variation curve. It is simply the system daily peak loads arranged in descending order. One of the most common risk indexes is the Loss of Load Expectation (LOLE), which is simply the expected number of days in the specified period in which the daily peak load will exceed the available generating capacity. The system is said to have adequate reliability if the LOLE is below a certain specified value. If the LOLE is unacceptably high, additional generating capacity is added to the system (This is a simple case for an isolated utility. In the real world, other alternatives are available, such as buying power from other utilities during peak load periods. Incidentally, this process is called "wheeling," and is discussed in detail in Reference [10]. Obviously, wheeling is not an option onboard a ship.). Of course, the procedure is complicated if the grid is such that not all power generated can be distributed to all loads.

Naval Ship Electric Load Estimation

Shipboard power systems are different in several ways that complicate analysis. Commercial power loads usually vary daily and seasonally. More power is demanded during the day, and when the temperature is at the extremes. The demand also varies relatively slowly, due simply to the high number of loads on the system "averaging out" over time. Shipboard loads vary rapidly, with a relatively low number of loads on the system. The number of generators is small (usually only three or four), and large

19

increases in demand have to be tolerated with little or no advance warning (as during battle). Often additional generators are required to be brought on line rapidly and at unplanned times. Therefore, the load cannot be modeled using the daily peak load method discussed above and Loss of Load Expectation is not a valid risk index.

The installed generating capacity of naval electric plants is currently determined using the following or a similar procedure [Refs 11 and 12]:

1. The maximum connected load is determined by simply adding all possible electric loads present on the ship. In the case of a new design, this is an estimated total load based on existing ship designs.

2. The maximum expected load is estimated for several ship conditions (e.g. at anchor, peacetime cruising, battle) by multiplying each individual load by a load factor [Ref 13]. The load factors represent roughly the percentage of time during each condition the load is physically on, and are used to account for the fact that not all loads are present at all times (the basis for these factors are past practice, and the origins of most have been lost in the mist of time).

3. The largest resulting load is termed the maximum functional load.

4. The maximum functional load is multiplied by a factor of 1.2, then again by another factor of 1.2 to obtain the maximum functional load "with margin." The 20% margins are for "acquisition" (growth in the electrical loads during design and construction of the ship) and "service life" (growth in the electrical loads during the life of the ship after initial construction).

20

5 The size of the installed generators is obtained by dividing the maximum functional load with margin by the factor [0.9 (n-1)], where n is the number of generators and 0.9 is a margin for generator control. The factor (n-1) is used to allow one generator to be out of service and still supply all electrical loads.

It should be obvious that if the above methodology is used on a ship with integrated electric drive and/or pulsed power weapons systems, the result could be an extremely large electric plant. This could make the ship larger and more expensive than necessary, potentially with very little benefit in overall system reliability. Several questions arise:

- What load factors should be used for the pulsed power and electric propulsion systems?
- Is it necessary to be able to supply enough power to go full speed and fire all weapons simultaneously?
- Is it necessary to be able to go full speed and fire all weapons simultaneously with one generator off line?

In addition, the above method does not address the adequacy or reliability of the system in any quantitative fashion. For example, a plant consisting of two generators, each large enough to carry the entire load, would meet the above criteria. This plant is very likely less reliable than one consisting of three or more smaller generators. The proposed improved methodology will address the issue of system adequacy. The issue of

21

security is not addressed since the control systems aspects of Naval shipboard electrical

plants are beyond the scope of this project.

Chapter 3. SMOKEY Development

The proposed improved methodology for sizing Naval ship electric plants has been incorporated into a computer program called SMOKEY. SMOKEY will **not** make a decision for the designer, but it **will** provide the information necessary to allow the designer to make a sound engineering decision based on reliability considerations. This chapter discusses the philosophy behind the program, as well as the numerical techniques embedded in the code.

Philosophy

In order to determine the "optimum" configuration for an electric plant, the designer must understand clearly what "optimum" means. The optimum plant for one ship will not necessarily be so for another. Obviously, the designer wishes to provide the most reliable plant possible. However, the constraints will vary from project to project. The total weight of the generators will be much more critical in a frigate design than a cruiser design, since the cruiser is so much larger. Cost is always an issue, but may not be as important on some projects as other factors.

Therefore, SMOKEY has been coded to compute and display reliability information as a function of total installed generating capacity, the total number of generators, total cost, and total weight. This allows the designer to optimize the plant

configuration as required by the design constraints important to the particular design. Fuel weight was not considered because the amount of fuel required to be carried on board a ship is a complex function of the ships mission, specified endurance range and speed, the shape of the tanks, engine specific fuel consumption, expected electrical load, and numerous other factors. Since this would greatly complicate the development of the program, as well as increase the amount of information needed to run the program and potentially make it harder to learn to use, the fuel consumption was not included as a parameter in the first version of SMOKEY.

SMOKEY was initially conceived as a design tool for use during the earliest phases of ship design. During these early phases, the design changes rapidly. A Navy ship design is a study in compromise; no ship is optimum in all respects. Therefore, many tradeoff studies are conducted to help the ship designers, managers, policy makers, ship builders, politicians, and other government officials involved in the process decide on the characteristics of the ship. In this environment, the designer of the electric plant is required to evaluate numerous potential configurations of generators and loads. The most important consideration for the program, then, was that it be easy to learn and use. If the program is not easy to use, it would not be used no matter how good it was (witness the proliferation of so-called "shelfware" in most offices). In addition, the program should be able to run on a personal computer, since a mainframe would not always be available.

Interest in the issue of sizing electric plants was brought about by the work currently being done on electric drive. However, it would be narrow minded to think that only electric drive ships will be built in the future. It was considered important, then, to make SMOKEY usable for non-electric drive ships as well. This is accomplished easily, and is a matter of simply inputting the proper loads. This point will become clear as the program is described in detail later in this chapter.

Based on the above discussion, it was decided the program should allow the user to input load information, then several potential generator configurations (capacity, availability, weight, and cost of each generator). The program would compute a reliability index for each configuration, and display the information graphically so that the user could see which configuration was best in terms of the parameter (cost, weight, etc.) of most significance. This would also allow cost-benefit analyses to be performed easily, as the user could see graphically the point at which the addition of more capacity (another generator, or larger generators, for example) produces a marginal increase in reliability.

The problem then became one of developing a suitable reliability index. Generator information for each configuration could be manipulated into a capacity outage probability table. As discussed previously, the utilities would then combine the load model with the table to determine the reliability index. The Navy equivalent of the daily peak load variation curve would be a load curve based on a ship operating profile. That is, an operating profile would be postulated (transits at certain speeds, battle

engagements, etc.), then the electrical loads for each operating condition calculated to produce an "electric load operating profile." This load profile would be combined with the capacity outage probability table to produce an index similar to the LOLE. However, there are several problems inherent in this type analysis:

1. What operating profile should be used? Shipboard electric loads vary greatly with temperature, and so would vary greatly with time of year and operating area. Since the United States Navy operates all over the world year round, the operating profile would have to be very specific and complex. Furthermore, the missions of ships tend to change over their twenty to thirty year lives (for example, the recent breakup of the Soviet Union has changed the entire focus of Navy ships from open-ocean superpower conflict to shallow-water coastal warfare and humanitarian missions). Therefore, the development of an accurate operating profile would be a complicated matter indeed!

2. Development of an accurate load profile would require detailed analysis of the loads which would be time consuming at best; not possible at worst.

3. What would the index mean? An index similar to the LOLE would provide an expected number of days (or hours, etc.) that the ship could not supply the expected electrical load. That is, you would be telling the Captain that he has a ship that cannot perform its specified mission for some portion of the time. The last thing the Captain wants to hear is that his ship is expected to not be able to perform, particularly in the heat of battle!

Therefore, it was decided that an appropriate index would be a simple one: the probability that the plant could supply given percentages of the loads at any random time (for example, the probability that the plant could provide 75% of propulsion power, 50% of weapons power, and all vital loads). This could easily be computed from the capacity outage probability table given the total load in question. The problem then became one of how to input the loads, and what the percentages should be.

Based on the experience of the author, review of several ship electric load analyses and reports [Refs 14, 15, and 16], and discussions with Navy ship design engineers, it was decided to group loads into four categories: vital loads (loads that must be supplied at all times), weapons systems loads, propulsion loads, and damage control loads. Also, since the percentages of interest would be different for different ships, it was decided to let the user select the percentages. This provides the additional benefit of allowing the user to evaluate several possible operating conditions for each potential generator configuration.

Methodology

Because of the desire to run SMOKEY on a personal computer and make it easy to use, it seemed natural to write the program as a Windows application. The graphical user interface (GUI) would greatly enhance usability, and the popularity of the Windows operating system would ensure the program could be used by virtually anyone in need of it. These factors, combined with the authors familiarity with the BASIC language (not to

27

mention **total unfamiliarity** with the "C" family, the other popular Windows

programming language system), conspired to force the selection of VISUAL BASIC for

WINDOWS [Ref 17] as the language to be used in developing SMOKEY. In addition,

the recent release of VISUAL BASIC for DOS would allow SMOKEY to be compiled

nearly unchanged for use as a DOS application, complete with a GUI, should that be

necessary.

The methodology of SMOKEY is simple and straightforward. The user is

prompted for all input, which is entered using the keyboard and/or mouse (or other

pointing device). Electric loads are input in four groups as described above. The

percentages of weapons, propulsion, and damage control loads to be considered are then

selected. The total load to be used to enter the capacity outage probability table is

calculated as the sum of the given percentages of those loads plus 100% of the vital

loads. The generator information is then entered, and the capacity outage probability

table computed. The total load is compared to the table, and the reliability index

computed and displayed. The user can then input additional generator configurations,

compute the indices, and display plots as described earlier. Printed output of the plots

can be obtained by selecting "Print" from the menu of the desired graph.

Perhaps the most interesting aspect of SMOKEY is the method used to compute

the capacity outage probability table. Reference [9] provides a recursive method for this

computation. However, this method proved difficult to code. Instead, a method based

on Z-transforms was used. This requires some explanation.

A probability mass function (PMF) is a function for a random variable x, say $p_x(x_0)$, defined [Ref 18] as follows:

$p_x(x_0)$= probability that the experimental value of random variable x is equal to x_0.

Since each generator is modeled as either available or not available (no derated states are allowed on Navy ships), the PMF for each generator is simply an impulse at the rating point of magnitude A (where A is the availability of the generator), and an impulse at zero of magnitude (1-A).

The Z-transform is defined [Ref 18] as:

$$p_x^T = \sum_z z^{x_0} p_x(x_0)$$

The Z-transform for each generator PMF then becomes:

$$p_x^T = (1-A) + Az^{(kW)}$$

where kW is the rating point of the generator.

When two or more generators are added, the combined PMF (which is, basically, the capacity outage probability table) is the **convolution** of the separate generator PMFs (assuming statistical independence, which is a valid assumption here since the availability of each generator is independent of all the others), which is a complicated

series of infinite integrals. However, the Z-transform of the combined PMF is the **product** of the Z-transforms of the separate generator PMFs, which is a much simpler operation. SMOKEY computes the capacity outage probability table by computing the product of the Z-transforms of the separate generator PMFs.

Validation

The computations made by SMOKEY were validated in three ways:

1. Comparison to examples presented in Reference [9].

2. Comparison to hand computations using the binomial distribution of Reference [8]. This is valid when the generators are identical.

3. Comparison to results produced by TIGER. The TIGER runs are provided as Appendix (B), and are for the following cases: 1 of 2 identical generators necessary to supply the load, 2 of 3 identical generators necessary, and 2 of 4 generators necessary. The appropriate numbers for comparison from the TIGER runs are the average availabilities and estimated long-term availabilities for the system. TIGER outputs much more information which is not necessarily useful in this case. Also, it should be noted that TIGER outputs a parameter called "reliability." This parameter is defined by Reference [5] specifically for the TIGER simulations, and is not appropriate for use here.

The computations made by SMOKEY were exact for 1 and 2 above, and within 3% for 3. The differences in the SMOKEY and TIGER runs are attributed to the different methods of calculation employed. SMOKEY uses deterministic methods, while TIGER used Monte Carlo methods, as discussed previously. Based on the above, the operation of SMOKEY is considered validated.

Chapter 4. SMOKEY Program Operation

SMOKEY is an interactive program which takes all input from the keyboard and outputs to the screen. Plots can be printed if desired. The source code for SMOKEY is included as Appendix (A). This chapter describes the code in detail and explains the operation of the program.

Installation

In order to ensure proper setup of the program and make installation as easy as possible, an installation program was developed for SMOKEY. The installation program is also a Windows application. Therefore, Windows must be running during the installation process. Installation of SMOKEY is performed as follows:

1. The SMOKEY disk should be inserted in the appropriate disk drive. From the Program Manager, select the File menu, then the Run command. In the Run dialog box, type "a:setup" (or "b:setup" if the disk is in the b-drive, etc.) in the Command Line box. This starts the Setup program.

2. The Setup program first checks to ensure the hard disk has enough space to accommodate all the SMOKEY files. If so, it prompts the user for the directory in which to install SMOKEY (the default is c:\smokey). If the selected directory does not exist, the Setup program creates it.

3. The Setup program then copies the executable file SMOKEY.EXE into the specified directory. In addition, several other files are copied into the windows\system subdirectory:

      a. VBRUN200.DLL: This is the Visual Basic 2.0 run-time library, and is required for any program written in Visual Basic 2.0 to run.

      b. GRAPH.VBX, GSWDLL.DLL, and GSW.EXE: These files are from the Visual Basic Toolbox, and are necessary for the graphing subroutines to run.

The Setup program checks to see if these files are already installed, and only replaces them if the version on the SMOKEY disk is more recent.

4. The Setup program then installs a Program Manager group called SMOKEY, and an icon for SMOKEY in that group. The icon can be moved into any group and the SMOKEY group deleted if desired.

5. SMOKEY can now be started the same way as any other Windows program (by double clicking on the icon, etc.).

Using SMOKEY

Once the installation process is complete, SMOKEY is started in the same way as any other Windows program. The details of how to use the program will be discussed in the next section, which describes the subroutines in detail. Basic familiarity with the

Windows operating system is assumed. Readers unfamiliar with Windows should refer to the Microsoft Windows User's Guide, or any of a number of other Windows references currently available.

Subroutine Description

Each screen in Visual Basic is called a form. Subroutines are then attached to the form (e.g., each button or menu on the form will have an associated subroutine which is executed when the user selects that item). Therefore, the explanation of the program will proceed from form to form for ease of understanding. Since the forms are in color, they cannot be reproduced exactly here. It should be noted that SMOKEY was written for Windows version 3.1. It will run with earlier versions, but the appearance of the forms, especially the text fonts, may differ from those pictured.

General

Forms are manipulated as with any Windows program. Menu items are accessed using the mouse or the keyboard (i.e. ALT+ the underlined menu item letter). Forms may be moved around the screen by "drag and drop" with the mouse.

Each form, with the exception of the startup, error and message forms, has the menu items "File" and "Help" at the top of the form. The "File" menu contains a submenu item "Exit" which will terminate the program when selected. The "Help" menu

34

contains a submenu item "About," selection of which causes the Figure 1 information

form to be displayed.
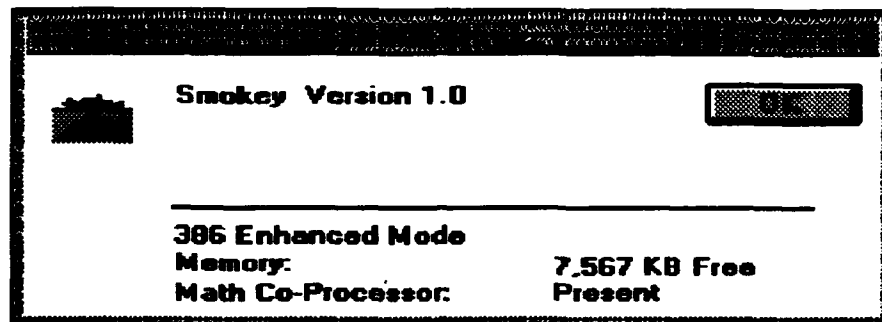
Figure 1. Information Form

This form displays information about the computer on which SMOKEY is running. In

particular, the Windows mode, amount of free memory, and whether a math co-processor

is installed in the system are displayed.

Startup Form

When SMOKEY is started, all variables and arrays are set to zero. The Figure 2

startup/copyright form appears.
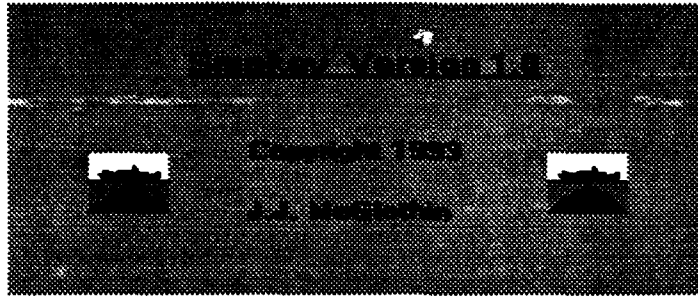
Figure 2. Startup Form

This form is displayed for approximately two seconds. Then, the timer function associated with this form opens the Load Information Input form and closes the startup form.

Load Information Form

The Figure 3 Load Information Form receives the load information. Loads in each category are input by placing the cursor in the appropriate box (with the mouse or tab key) and entering the load values from the keyboard. If no value is entered into a box, the program assigns a value of zero to that load category.

Figure 3. Load Information Form

The OK button causes the load values to be stored. The Reliability Index

Selection form is then opened and the Load Information form closed. It should be noted

that the Non-Vital Load is not included in the total load calculation. Therefore, no value

is required in this input box. The Non-Vital Load box was included for possible use in

future revisions of SMOKEY.

Reliability Index Selection Form

The Figure 4 Index Selection Form allows selection of the percentages of each load category for use in the total load calculation.

Figure 4. Reliability Index Selection Form

The percentages are selected by manipulation of the scroll bars with the mouse, or by typing the numbers directly into the input boxes. The numbers should be entered as percentages rather than decimals (i.e. 45 for 45%, not 0.45). The OK button causes the total load to be calculated and stored (the total load is the vital load plus the sum of the selected percentages of the other load categories), the Generator Input form to be displayed, and the Index Selection form to be closed.

Generator Input Form

The Generator Input Form does most of the work of SMOKEY, and is shown in Figure 5. The information for each generator is input as with the other forms. It should be noted that the parameter "Reliability" is actually the availability of the generator. The Generator Number box displays the number of the next generator to be input into the configuration (this is displayed by the program and does not have to be input by the user). Each generator is added by selecting the Input button. This causes the weight, cost, and capacity information for the generator to be added to the total for the configuration, and the generator to be added to the capacity output probability table (using the Z-transform method described earlier). When the last generator has been input, the Finished button should be selected. This causes the total weight, cost, capacity, and number of generators for the configuration to be stored in an array. The total load is then compared to the capacity outage probability table, and the reliability index computed. The result is displayed in the box near the bottom of the form and stored in an array. If there is insufficient capacity to supply the load, the error message form shown in Figure 6 is displayed.

Generator Number

Capacity   KW

Reliability   0-1.0

Weight   LTons

Cost $

The probability that the configuration will be
able to supply the loads at any random time is

Figure 5. Generator Information Input Form

Selection of the Next Config button allows another generator configuration to be

input in the same way as before. The weight, cost, capacity, and number of generators

for each configuration, as well as the reliability indices, are stored for graphical display.

Selection of the Graphs button closes this form and opens the Graph Forms.
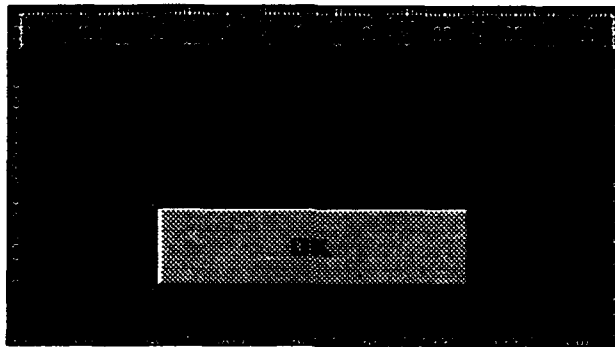
Figure 6. Insufficient Capacity Error Form

As will be discussed later in this chapter, the maximum number of generators which can be input into any configuration is twelve. Therefore, if a twelfth generator is added, the Figure 7 Message form is displayed to inform the user they cannot add more generators to that configuration.
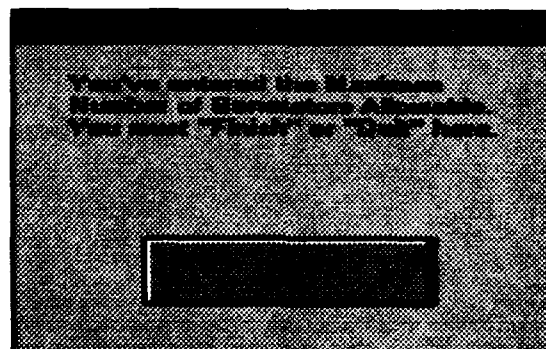
Figure 7. Maximum Number of Generators Message Form

Comparison Plot Forms

The Graphs Forms display total cost, total system capacity, total weight, and total number of generators for each configuration against the selected reliability index. A typical graph is shown in Figure 8. The graphs allow the user to see the point at which addition of capacity does not produce an appreciable increase in system availability.
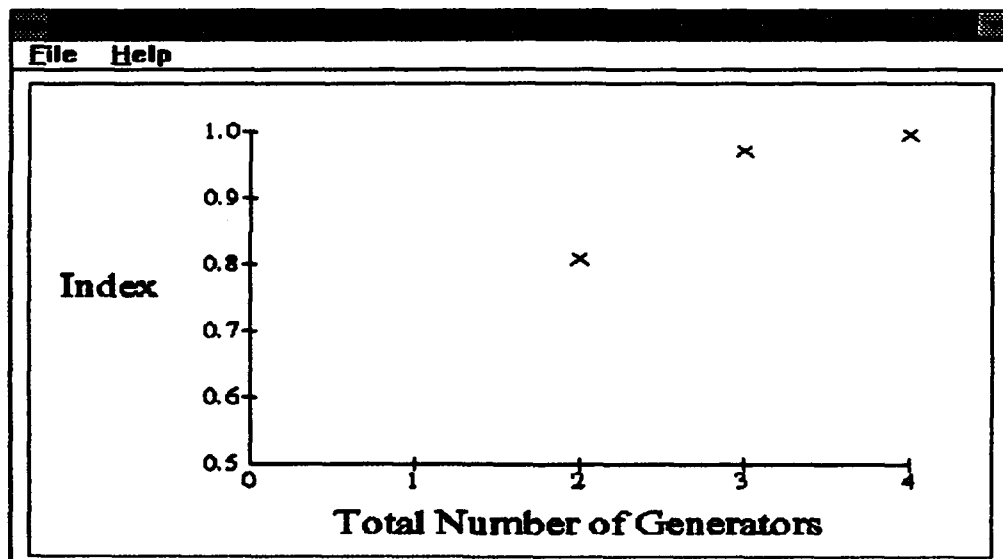
Figure 8. Reliability Index Graph Form

The plots can be printed by selecting the Print option under the File menu. The print routine uses the Windows printing functions, so no separate printer drivers are necessary. The program will print to the default printer, as long as it will support graphics printing. The program terminates if all the Graph Forms are closed, or if the Exit option is selected under the File menu of any of the Graph Forms.

Other Subroutines

SMOKEY incorporates some error checking to prevent inappropriate data from being entered. If any inappropriate data are detected (reliability greater than 1.0, etc.), the Figure 9 Error Form is displayed.
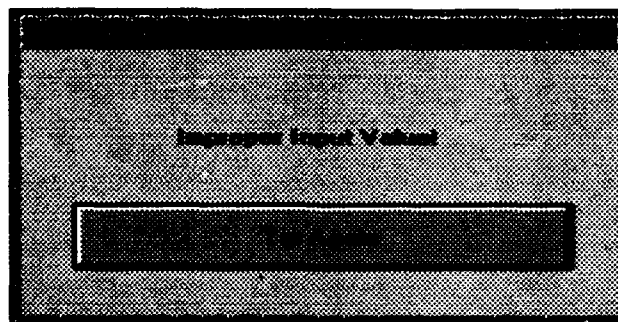
Figure 9. Improper Input Error Form

Unfortunately, due to time constraints, a separate form was not generated for every possible error. Therefore, the user must figure out which input value on the current form is improper, and change it before being allowed to continue.

Program Limitations

There are several limitations inherent in the operation of SMOKEY which should be mentioned. The limitations, and reason for each, are as follows:

1. The maximum number of generators that can be input into a single configuration is 12. This is due to the fact that the program was originally written in Version 1.0 of Visual Basic, which had an inherent array size limitation. Visual Basic Version 2.0 has no such limit. However, the SMOKEY code has not yet been revised to remove the 12 generator limit.

2. The maximum number of generator configurations which can be compared and plotted is 10. This limit was written into the code to prevent the plots from getting too "busy" to be useful.

3. The individual points on the comparison plots are not labeled. This means the user has to track the results computed by the Generator Input Form well enough to be able to distinguish which point belongs to which configuration. This is due to the fact that the graphing routines built into Visual Basic 2.0 (Professional Edition) were used to save time, rather that writing custom routines. These routines do not allow individual points to be labeled.

Chapter 5. SMOKEY Application

The purpose of this chapter is to demonstrate the application of SMOKEY. Several cases are examined to illustrate the different ways in which SMOKEY can be used. First, the DDG-51 electric plant is examined, and the results compared to the Reference [19] reliability analysis. A hypothetical conversion of the DDG-51 to electric drive is then examined. Two cases are considered: Conversion to electric drive with propulsion derived ships service electric power (integrated electric drive), and conversion to electric drive without propulsion derived ships service power. Finally, to show how the program would be used during design of a new ship (rather than evaluation of an existing design), the propulsion plant of a proposed Heavy Lift Ship is evaluated. This ship is being designed as a graduate student design project in the Ocean Engineering Department at MIT.

Information on several prime mover-generator combinations is summarized in Table 1. These units are used throughout the examples of this chapter. Table 1 is not intended to include all units available for possible use in Naval ships. However, it does represent a reasonable cross-section of available units, and provides enough choices to adequately demonstrate SMOKEY. The examples of this chapter are intended to illustrate the use of SMOKEY and its methodology in making decisions relative to installed electrical generating capacity in Naval ships. They do not represent recommendations on the part of the author for potential ship conversions. Any such

extensive modifications as changes in an existing ship propulsion plant would require much more detailed evaluations (since many secondary effects would have to be considered, such as changes in weight affecting draft, stability and seakeeping characteristics), and are beyond the scope of this chapter.

Table 1. Generator Information

Generator	Capacity(kW)	Availability	Cost($M)	Weight(ltons[1])
Allison[2]	2,500	0.9347	2.3	26.9
CAT 3612[3]	3,300	0.9347	1.24	45.54
LM2500/ED[4]	18,600	0.9389	8.2	81
LM2500[5]	19,500	0.9389	8.6	85
2.5 Diesel[6]	2,500	0.9964	2.1	44.4
3.75 Diesel[6]	3,750	0.9964	2.5	59

Notes:

1. "Lton" is an abbreviation for "Long Ton," which is 2,240 pounds. This is the common weight unit used in naval architecture.

2. All information from Reference [20], with the exception of availability which was calculated from information in Reference [19].

3. All information from Reference [20], with the exception of availability, which was assumed to be the same as the Allison because of a lack of reliability data on this unit.

4. All information from a preliminary report from the Advanced Surface Machinery Project Office, with the exception of availability which was calculated from Reference [19] (assuming the standard LM2500 with a typical electrical generator). The "ED" designation is for "Electric Drive," to distinguish this unit from the next one in the table.

5. This unit is a standard LM2500 with a larger generator than the previous unit, intended to use more of the available power of the gas turbine. The weight and cost were scaled up from the previous unit, and availability calculated from Reference [19].

6. Cost and weight information taken from a preliminary report from the Advanced Surface Machinery Project Office. Availability assumed to be that of a typical diesel generator provided in Reference [21].

The first four units in Table 1 are gas turbine driven. The third, fifth and sixth units have been defined by the Advanced Surface Machinery Office as "standard modules" for use in Naval propulsion plants as part of the Navy "affordability through commonality" initiative. It should also be noted that Reference [19] identifies some components of the gas turbines as not repairable by ships force. To calculate an availability for the unit, a MTTR of twenty days was assumed for those components.

This assumption is consistent with the logistics delay of twenty days assumed in the Reference [19] analysis for all parts not available on board.

DDG-51 Electric Plant Analysis

The simplest application of SMOKEY is to analyze an existing electric plant. Since a detailed load analysis has been performed and the installed plant proven satisfactory, it is prudent to compare possible configurations in terms of the load used to design the plant originally. The intent here is to evaluate the DDG-51 plant and compare the results obtained using SMOKEY with the Reference [19] analysis (which used the Monte Carlo methods of TIGER [Ref 5]). It should be noted that Reference [19] is very extensive, and the electric plant only one of many systems analyzed. However, the pertinent electric plant information can be extracted for comparison. The current DDG-51 electric plant consists of three 2500 kW Allison gas turbine generators.

Reference [14] calculates a maximum functional load (using the method discussed in Chapter 2) of 3990 kW. This load was used as the design load for the DDG-51 electric plant. Many operating conditions analyzed in Reference [14] require total loads less than 2500 kW and would therefore require only one generator. However, standard practice is to run two of the three generators at all times to prevent the loss of one generator from making the ship "cold and dark." Therefore, the Reference [19] analysis assumed two generators were required at all times.

Reference [19] simulated the electric plant as three Allison gas turbine generators, two of which were required to be running at all times. The availability for the sixty day mission was calculated as 0.98. However, Reference [19] recommended the addition of a fourth generator based on the fact that the gas generator of the gas turbine, which is not repairable by ship's force, accounted for 16% of the unavailability of the ship.

The benefits of adding a fourth generator can easily be analyzed using SMOKEY. By using the design load (3990 kW) as the "vital" load and zeros for the other load categories as inputs, the results produced by SMOKEY become simply the probability the system can supply the design load. This could alternately be considered the overall availability of the system. This probability for the current configuration (3 installed generators) is 0.9878, which compares well with the Reference [19] analysis. The probability with four generators is 0.9989. Therefore, the addition of a fourth generator increases the probability that the system can supply the design load by less than 2%. This is shown graphically in Figure 1 (Note: All graphs in this chapter were produced by SMOKEY).
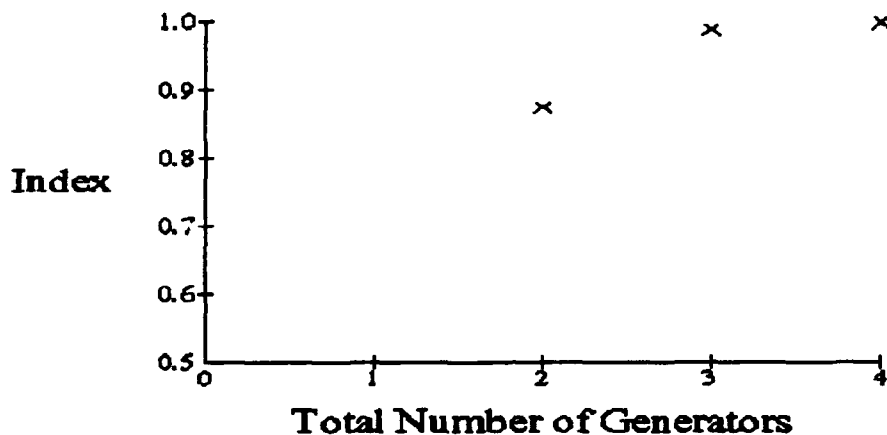
Figure 1. DDG-51 Addition of Fourth Generator Analysis

Figure 1 shows clearly that the addition of a fourth generator is not beneficial enough to warrant the extra cost or weight. However, it should be mentioned that other considerations, such as a damage analysis [Ref 3] considering physical location of each unit, might show additional benefit in the addition of a fourth generator.

Other alternatives can be analyzed. SMOKEY was used to evaluate the potential replacement of the Allison units with other appropriate units of Table 1. The results are provided in Table 2. For simplicity, no mixed cases (i.e. all units were assumed identical) were considered.

Table 2. Probability of Supplying DDG-51 Design Load

Generator	Number of Generators				
	1	2	3	4	5
Allison	0	0.8737	0.9878	0.9989	0.9999
CAT 3612	0	0.8737	0.9878	0.9989	0.9999
2.5 Diesel	0	0.9928	0.9999+	0.9999+	0.9999+
3.75 Diesel	0	0.9928	0.9999+	0.9999+	0.9999+

Table 2 shows that three is the "correct" number of generators no matter which units are used, since the addition of the fourth produces little benefit in any case. The 2-diesel configurations are not considered correct, even though they are more reliable than the current configuration, since all installed units would be required to be on line at all times (given the current operating practices). Such a situation would make maintenance at sea difficult. Some other observations can be made:

- Increasing the size of the units in itself produces no benefit since none of the units are large enough to carry the design load on one generator.

- Changing to diesel generators increases the reliability of the system due to the higher availability of the diesel.

SMOKEY can also be used to evaluate the 3-Allison system against the 3-2.5 Diesel system. The data from Table 2 show that the diesel plant is slightly more reliable. Also, Figure 2 shows a small cost savings in switching from a gas turbine to a diesel driven plant (the left point is the diesel plant). However, Figure 3 shows the diesel plant to be significantly heavier (the left point is the Allison plant). Therefore, the benefit of changing to diesel is probably more than offset by the disadvantage of increased weight. The installed plant is therefore the "best" available in terms of the design load and the available choices.
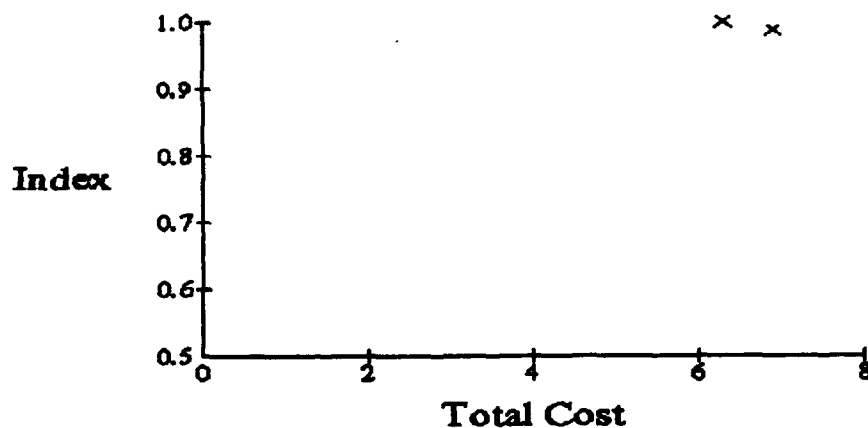
Figure 2. Cost Comparison: 3-Allisons vs. 3-2.5 Diesels (cost in $M)
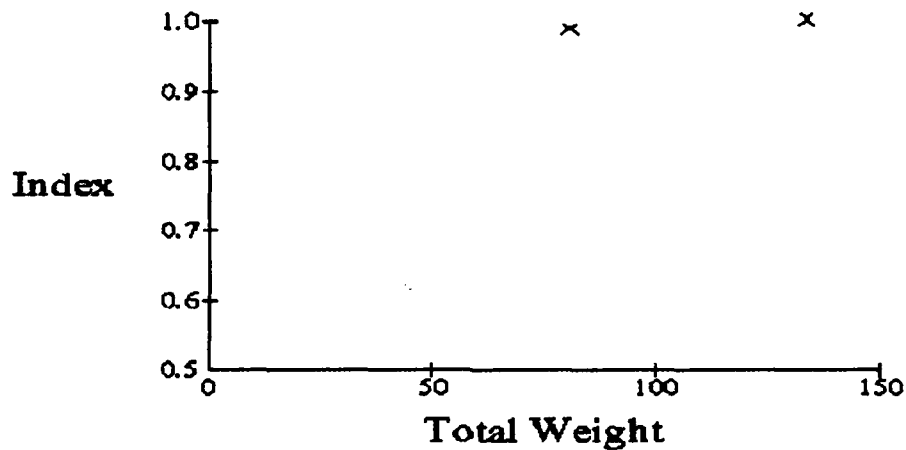
Figure 3. Weight Comparison: 3-Allisons vs. 3-2.5 Diesels (Weight in Long Tons)

Electric Drive DDG-51 Analysis

The next case to be considered is a hypothetical conversion of the DDG-51 to electric drive. In this instance, the propulsion and ship service electric systems remain separate. That is, the propulsion generators generate electric power only to turn the propellers. There is no propulsion derived ships service (PDSS) power.

A similar study was performed in Reference [22] for the DD-963 Class ships. However, the purpose of the Reference [22] study was to demonstrate the feasibility of using superconducting equipment in an electric drive ship and the benefits of using such an arrangement. Since a detailed design evaluation is beyond the scope of this project and the purpose here is purely illustrative, the following simplifying assumptions (and

the resulting differences between the Reference [22] study and the following example) have been made:

1. The ship hull form and draft, and therefore the amount of power necessary to propel the ship through the water, are assumed constant. The Reference [22] study allowed the ship to change size in response to the size and weight changes in the propulsion plant in order to more accurately access the impact of the electric drive propulsion plant.

2. The propellers are assumed to be the same. Gas turbine driven ships with conventional mechanical drive have propellers which change pitch to vary the amount and direction of thrust (called "controllable reversible pitch," or CRP propellers). This is necessary since gas turbines operate at constant speed and in only one direction. In reality (as assumed in Reference [22]), an electric drive ship could use fixed pitch propellers (since the control system could change the speed and direction of rotation of the propulsion motors independent of the gas turbine speed) which are more efficient and more reliable.

3. Only changes in prime movers and generators are considered. In reality (as considered in Reference [22]), changing from reduction gears, couplings and long shaft runs to generators, motors and relatively short shaft runs would have potentially large effects on the ship.

4. The reliability characteristics of the reduction gears, shafting, propulsion motors, propellers, etc. is ignored. This is an oversimplification, but is appropriate here since the example is for illustrative purposes only.

Table 3 summarizes the calculations made for this example. The numbers in the table represent the probability that the configuration can propel the ship at the indicated speed at any time. The "As-Is" configuration is the present DDG-51 plant: two shafts, each powered by two LM2500 gas turbines coupled through a reduction gear. The following procedure was used in developing Table 3.

1. The "As-Is" numbers were calculated using the availability for the LM2500 only (0.9391, calculated from Reference [19] data), which is slightly higher than the LM2500 of Table 1, since the generator is not present. Both shafts were assumed to be required; one turbine per shaft at a speeds less than 27 knots, two turbines per shaft at speeds above 27 knots. This is technically not true. One shaft could propel the ship at a significant fraction of top speed. However, this situation is not preferred, and is more difficult to analyze. The probabilities were then calculated using the binomial distribution [Ref 8]. The lower speed numbers appear low at first glance. The reason is that the probability is not that at least two of the four gas turbines be available, but that at least one of two for one shaft and at least one of two for the second shaft be available. Of course, the probability for the higher speeds is the probability that four of four gas turbines are available.

2. For the electric drive numbers, the higher power LM2500 unit of Table 1 was used. The required powers were calculated from the Appendix (C) powering information as follows: The effective horsepower provided by ASSET is the power required to push the ship through the water at the indicated speed. The

propulsive coefficient is defined as the effective horsepower divided by the total shaft horsepower (since the propellers are not 100% efficient). The effective horsepower was divided by the propulsive coefficient to determine the required shaft horsepower. This was then divided by 0.9 to approximate the losses in the electrical system between the generators and the propellers. The required power was then used as the vital load input into SMOKEY.

3. Because of the assumptions made and the procedure used for calculating required power, the three LM2500 electric drive ship is unable to go 30 knots. More detailed calculations would be required to access whether this was really true, since this ship would potentially be at least 80 long tons lighter that the others.

It should be noted that the Appendix (C) information is obtained from ASSET, and is not actual DDG-51 data. Rather, it is a computer model that has been matched closely to the existing ship.

Table 3 shows the 4 LM2500 electric drive configuration to be the more reliable propulsion system. The slightly higher numbers for the As-Is configuration at the highest speeds is due to the slightly higher availability of the LM2500 without the generator. Even so, the difference is very small and is more than outweighed by the superiority of the electric drive configuration at the lower speeds. This is due to the fact that power from any of the generators can be distributed to either shaft, unlike the mechanical drive arrangement. As stated previously, the lower top speed of the electric

56

drive ships is a function of the simplifying assumptions made and would probably not exist should a detailed evaluation be performed.

Table 3. Probability of Making Indicated Speed

Speed (knots)	As-Is	Electric Drive 3 LM2500s	Electric Drive 4 LM2500s
20	0.9926	0.9998	0.9999+
22	0.9926	0.9998	0.9999+
24	0.9926	0.9893	0.9991
26	0.9926	0.9893	0.9991
28	0.7778	0.8277	0.9794
30	0.7778	0	0.7771
31	0.7778	0	0.7771

It is difficult to accurately compare the two electric drive configurations. In all likelihood, the 3-generator ship would be smaller and lighter. This would increase the top speed and change the probabilities listed. However, for the sake of illustration, the following observations can be made:

- The 3-generator ship is very nearly as reliable as the 4-generator ship at speeds below about 28 knots.

57

- The top speed of the 3-generator ship is somewhat greater than 29 knots, while the top speed of the 4-generator ship is somewhat greater that 31 knots.

- The 3-generator plant would be at least 85 long tons lighter than the 4-generator plant, allowing for 85 long tons more payload.

- The 3-generator plant would be at least $8.6M cheaper than the 4-generator plant.

The ship designer, then, must decide which is more important: higher top speed or more payload and lower cost.

Obviously, the current practice of providing enough generating capacity such that the load can be carried with one generator off line is difficult to apply in the case of electric drive propulsion. Should the load considered be the maximum speed load, or something less? In the above example, a fifth LM2500 would be required if the maximum speed propulsion load were required to be carried with one generator unavailable, making the propulsion plant more reliable (not to mention expensive) than the existing ship. SMOKEY gives the designer a tool for accessing potential configurations in a much more reasonable way.

Integrated Electric Drive DDG-51 Analysis

The next case to be considered is the conversion of the DDG-51 to integrated electric drive. That is, electric power from any generator can be distributed to the ship service system and/or the propulsion system. In this example, mixed configurations will

be evaluated (i.e. not all generating units identical). While this type of evaluation is straightforward with SMOKEY, it is very difficult using TIGER or similar analysis tools, since the plant does not operate according to simple operating rules (i.e. two of three generators must be operating, etc.).

The analysis was performed as follows:

1. The design ship service electric load was input as the vital load. That is, the system was required to be able to supply 3990 kW to the ships service system at all times.

2. The 31 knot propulsion load calculated for the previous example (77,537 kW) was input as the propulsion load.

3. Several SMOKEY runs were made with various percentages of the propulsion load selected as the index. The output is then the probability that the electric plant can supply the design ship service load and the selected percentage of the propulsion load.

Several configurations were considered, all using the higher power LM2500s. First, three LM2500s alone, then with one, two, or three Allisons, 2.5 Diesels, or 3.75 Diesels (i.e. 10 combinations). The same combinations were then run again with a fourth LM2500 added. Only the addition of three 3.75 Diesels significantly changed the reliability of the plant. The results are summarized in Table 4. Note the three LM2500

ship again is not as fast as the four LM2500 ship. This is due to the fact that the hull form and draft were held constant as discussed in the previous example.

Table 4. Probability of Providing Design Ships Service Power and Selected Percentage of Propulsion Power

% Propulsion Load	Approximate Speed (knots)	3 LM2500s	3 LM2500s + 3 3.75 Diesels	4 LM2500s	4 LM2500s + 4 3.75 Diesels
80	30	0	0.8188	0.7771	0.9772
70	29	0.8277	0.8277	0.9794	0.9794
60	28	0.8277	0.8277	0.9794	0.9794
50	27	0.8277	0.9893	0.9794	0.9991
40	26	0.9893	0.9893	0.9991	0.9991

Table 4 shows the 4 LM2500 plant to be generally more reliable, as would be expected. Also, the addition of the 3 smaller generators is beneficial at some speeds. The question, then, is what is the price of that added benefit? Figure 4 shows the cost, and Figure 5 the weight of the generating plants of Table 4, using the 50% of propulsion power index. In Figure 4, the points are, from left to right, the 3 LM2500 plant, the 3 LM2500+3 Diesel plant, the 4 LM2500 plant, and the 4 LM2500+3 Diesel plant. In Figure 5, the order of the two middle points are reversed.
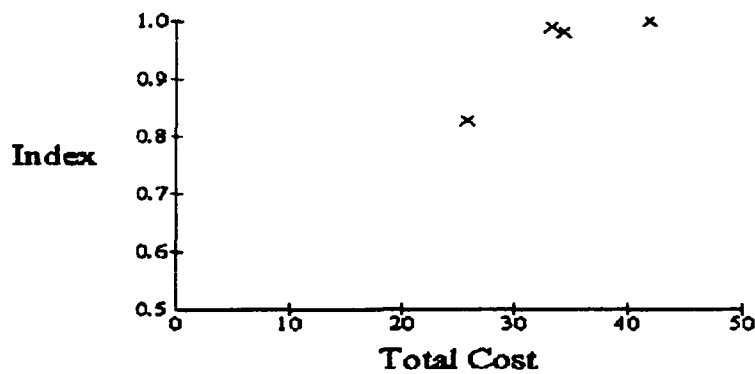
Figure 4. Cost Comparison: DDG-51 with Integrated Electric Drive (Cost in $M)
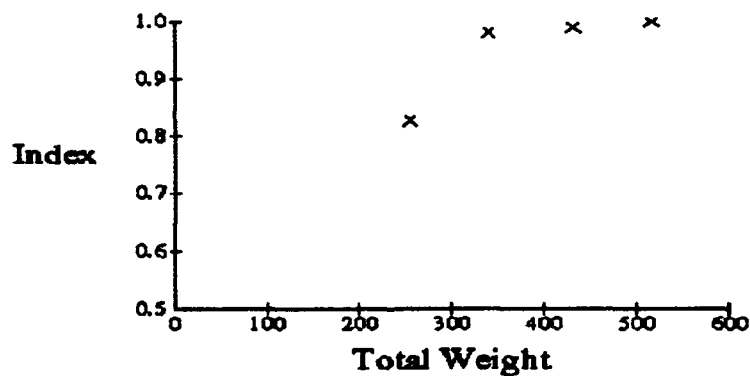
Figure 5. Weight Comparison: DDG-51 with Integrated Electric Drive (Weight in

Long Tons)

The following observations can be made from Figures 4 and 5:

- The 4 LM2500 + 3 Diesel plant is the most reliable, but is also the most expensive

  and heaviest.

61

- The cost of the 4 LM2500 plant is nearly the same as the 3 LM2500 + 3 Diesel plant, and the latter is slightly more reliable. However, the latter is heavier.

- The 3 LM2500 plant is the cheapest and lightest, but is the least reliable.

Based on the above, the best plant (under the assumptions previously discussed) would be either the 4 LM2500 plant or the 3 LM2500 + 3 Diesel plant, depending on the relative importance of weight and cost. In either case, the total number of generators is reduced (as compared to the current DDG-51) by converting to integrated electric drive.

Again, the "all but one" rule is difficult to apply, especially since the generators are of different sizes. SMOKEY makes this evaluation easily, and gives the designer the information necessary to make a logical decision.

Heavy Lift Ship Concept Design Analysis

The preceding examples have gone from very simple to more involved applications of SMOKEY, in order to introduce the reader to the capabilities of the program. The following example is intended to show how SMOKEY can be used during the early stages of a ship design.

The Heavy Lift Ship, designated HL(X), concept design is a graduate student design project currently in progress in the Ocean Engineering Department at M.I.T. Reference [23] reported on the progress of the design at approximately the halfway point

in the project. The ship is intended to transport and support four mine countermeasures ships to and from a hostile area for mine clearing operations. The ship has a large well deck for this purpose, and enough ballast tankage to allow submergence of the well deck to approximately twenty feet.

Because of the required layout of the ship and various safety factors (discussed in detail in Reference [23]), it was decided early on to use an integrated electric drive propulsion plant. This type plant is quite beneficial for this ship since the major electrical loads occur during different evolutions. The major loads on the plant consist of propulsion, ships service, repair shops, ballasting pumps, and providing power to the ships in dock or alongside. However, these loads do not all occur simultaneously. For example, at sea the load consists of propulsion, ships service loads, and providing power to the ships in dock. During a docking evolution, the load consists of ballast pumps and ships service. Because of the integrated electric drive arrangement, the plant can be designed for the worst case evolution (underway, since the propulsion load is by far the largest), and not for the total combination of all worst case loads.

Since the ship is big and expensive, it was also decided to use the common modules defined as part of the affordability through commonality program mentioned previously to reduce cost. That means the generating units available for use were the third, fifth and sixth units of Table 1.

The evaluation of alternate generator combinations for the selection of the HL(X) propulsion plant was performed as follows:

1. The propulsion load was estimated based on the Appendix (C) ASSET output in the same manner as for the DDG-51 propulsion load discussed earlier. Since the primary mission of the ship is to transport the mine countermeasures ships at a speed of 16 knots, it was considered appropriate to use this load in the reliability calculation. The 16 knot load was calculated to be 18,179 kW, which includes a fixed load of 250 kW for motors, fans, etc. required by the propulsion plant.

2. The total connected ship service loads were calculated in Appendix (D), also based on the Appendix (C) ASSET output.

3. The ships service loads were placed into two groups, depending on the relative importance of supplying them under worst case conditions. Group 1 consists of firemain loads (firemain is the water system used for damage control, etc.), lighting, and ventilation (total connected load=4912 kW). Group 2 consists of heating/cooling loads, fresh water production and heating, and handling and services loads (total connected load=9465 kW).

4. A suitable reliability index was determined to be the probability that the plant could supply the electrical load of the four ships in dock (400 kW), 100% of the 16 knot propulsion load, 65 % of the Group 1 ship service load, and 35% of the Group 2 ship service load.

5. SMOKEY was used to calculate the reliability index by inputting the Group 1 load as the Damage Control load, Group 2 as the Combat System load (the ship

64

has no weapons), the 16 knot propulsion load as the propulsion load, and the 400

kW for the ships in dock as the vital load. Using the percentages previously

mentioned, the data of Table 5 was produced.

Table 5. HL(X) Power Plant Comparison

Configuration Number	Number of LM2500s	Number of 2.5 MW Diesel Generators	Number of 3.75 MW Diesel Generators	Reliability Index
1	2	0	0	0.8815
2	2	1	0	0.8815
3	2	2	0	0.8815
4	2	3	0	0.9950
5	2	0	1	0.8815
6	2	0	2	0.9954
7	2	0	3	0.9963
8	3	0	0	0.9893

Based on Table 5, configurations 4, 6, 7, and 8 were chosen for detailed

comparison. Because of the size of the ship, weight is not very important. The

overriding consideration is cost. Figure 6 shows the system reliability as a function of

the cost for the four configurations. The points are, from left to right, configuration 6, 4,

7, and 8. Based on this data, configuration number 6 was selected for the HL(X)

propulsion plant.
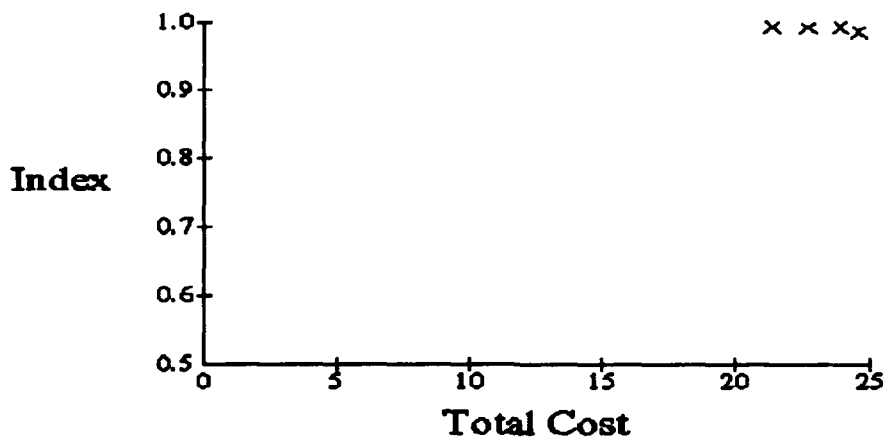
Figure 6. HL(X) Cost Comparison (Total Cost in $M)

The above example illustrates the need for the approach of SMOKEY. The current sizing methodology would be difficult if not impossible to apply in this case. For example, since not all the generators are alike, the "all but one" rule is again unclear. SMOKEY allows engineering judgment, combined with knowledge of the mission of the ship, to be used in the selection of the number, type, and size of the generators.

Chapter 6. Conclusions and Recommendations

The current methodology for sizing Naval ship electric plants has produced satisfactorily operating plants. However, there are shortcomings which are eliminated by the methodology proposed here, using SMOKEY:

1. The use of integrated electric drive. There is no "load factor" defined for the propulsion loads. What load should be used? SMOKEY allows the designer to select a proportion of the propulsion load appropriate to the mission of the ship being considered. SMOKEY also allows the reliability at different speeds to be computed for consideration by the designer.

2. The overall reliability of the generating system. The only requirement for reliability of the electrical generating system inherent in the current sizing methodology is the requirement that the plant be able to supply the estimated worst case load with one generator not available. This "all but one" rule is difficult to apply in cases where there is more than one type or size of generator present (such as the heavy lift ship presented in Chapter 5). Also, different types of generators (i.e. gas turbine driven versus diesel driven) have different reliability characteristics, which are not considered in the current methodology. Generators with higher availabilities would make the system more reliable, but might be undesirable for other reasons (heavier or more expensive). SMOKEY allows the designer to evaluate and compare configurations in terms of overall

system availability, cost, weight, and total number of generators (which is a measure of system complexity). SMOKEY also allows the comparisons to be made on systems consisting of different types and sizes of generators.

In conclusion, the methods demonstrated here using SMOKEY are an improvement to the current methodology. However, there are outstanding issues which must be addressed before the method can be implemented wholesale by the Navy:

1. Acceptable percentages of the total loads in the three categories used by SMOKEY (propulsion, combat systems, and damage control) need to be defined. The combat systems and damage control load percentages could be determined by analyzing current ship designs and comparing total connected loads to actual loads during different operating conditions. These would most likely be different for different classes of ships, so the analysis would be time consuming and require extensive amounts of data. The propulsion load percentage would most likely be determined on a case basis, depending on the mission of the ship.

2. A method for accounting for the presence of pulsed-power weapons should be developed. Most likely, this would involve separately analyzing the plant during operation of the weapon (since large amounts of power during some charging time would be required) and without operation of the weapon. In the case of a ship with integrated electric drive propulsion, operation of the weapon might involve a reduction in speed during the charging cycle.

3. Fuel consumption should be addressed earlier in the design process. Currently, the fuel required to be carried on board is based on the fuel consumption of the propulsion and ship service electrical generator engines at a single load value. In a ship with integrated electric drive propulsion, this calculation becomes even more difficult since power from any generator can be used for propulsion and/or ships service electrical loads, causing the operating points to vary. The required fuel calculation method should be reevaluated for electric drive ships.

There are also improvements which can be made to SMOKEY (which the author did not have time to do) which would improve the usability and usefulness of the program:

1. The limit on the number of generators which can be entered into a single configuration should be removed. Some very large ships (such as aircraft carriers) might conceivably require more than twelve generators.

2. The limit on the number of configurations which can be evaluated and plotted in a single run should be removed, since it was an arbitrary limit based on the graphical output. The user should be allowed to try as many plant configurations as desired, then rerun the program with the best candidates if the graphs are too busy.

3. The program should be revised to allow restarting without exiting totally. This would save time (and aggravation on the part of the user) when evaluating several loading cases.

4. The capability to input a ship operating profile rather than a single load index should be considered. This would complicate the program, but would provide the designer an additional basis for comparison between plants with similar reliability characteristics at the single load index chosen. This would probably be most appropriate for auxiliary ships, since there operation is much more predictable than a combatant and a reasonably accurate operating profile could be developed.

5. The program should consider fuel consumption. This is a difficult problem because of the complex way in which fuel requirements are presently calculated. Therefore, this improvement would probably best be made after the fuel requirement calculation method was reevaluated for electric drive ships.

6. The program should consider the area and volume required by the generators, as well as the cross sectional areas of the intakes and exhausts. The total area and volumed required by the plant are important factors in the design of a ship, and should also be used when comparing candidate configurations.

Overall, the methodology of SMOKEY is sound and removes some of the weaknesses of the current method. More work is necessary, however, for the program to be made fully applicable and usable for all ships.

References

[1] Doerry, N.H., "Advanced Numerical Methods for Simulating Nonlinear Multirate Lumped Parameter Models," Thesis, Ph.D., M.I.T., May 1991.

[2] Amy, J.V., "Composite System Stability Methods Applied to Advanced Shipboard Electric Power Systems," Thesis, Ph.D., M.I.T., May 1992.

[3] Whitcomb, C.A., "Composite System Analysis of Advanced Shipboard Electrical Power Distribution Systems," Thesis, Engineer, M.I.T., May 1992.

[4] Department of Defense, Interface Standard for Shipboard Systems, Section 300A, Electric Power, Alternating Current, MIL-STD-1399(NAVY), 13 October 1987.

[5] NAVSEA Technical Manual TE660-AA-MMD-010, TIGER Users Manual, Version 8.21, September 1987.

[6] Fink, D. and H. Beaty, Standard Handbook for Electrical Engineers, 12th Edition, McGraw Hill, 1987.

[7] Billinton, Roy and Ronald N. Allan, Reliability Assessment of Large Electric Power Systems, Kluwer Academic Publishers, 1988.

[8] Billinton, Roy and Ronald N. Allan, Reliability Evaluation of Engineering Systems: Concepts and Techniques, Plenum Press, 1983.

[9] Billinton, Roy and Ronald N. Allan, Reliability Evaluation of Power Systems, Plenum Press, 1984.

[10] Kelley, K., "Some Economic Principles for Pricing Wheeled Power," NRRI-87-7, 1987.

71

[11] Course Notes for M.I.T. Course 13.412, Principles of Naval Ship Design, Fall Semester 1991.

[12] Graham, C. and J. Hamly, "Simplified Math Model for the Design of Naval Frigates," Revision 3, 1 August 1991.

[13] Department of the Navy Design Data Sheet 310-1, Electrical System Load and Power Analysis for Surface Ships, 1 July 1980.

[14] Gibbs and Cox Drawing Number 3003-0005 Revision M, DDG-51 Electric Load Analysis, 20 September 1988.

[15] Ship System Status Program, USS JOHN F. KENNEDY (CV 67) Electrical System Baseline Report, 4 June 1991.

[16] Draft Report: Advanced Electrical Systems for Future Navy Surface Combatants, Westinghouse Electric Corporation, 18 June 1992.

[17] Microsoft Visual Basic Programming System for Windows, Version 2.0, Programmers Guide, 1992.

[18] Drake, Alvin W., Fundamentals of Applied Probability Theory, McGraw-Hill, 1967.

[19] Naval Sea Systems Command Report 05MR-004-84, DDG-51 Guided Missile Destroyer Contract Design Reliability, Maintainability, Availability Analysis, September 1984.

[20] Carmichael, A.Douglas, Mark A. Hugel and Mark T. Stanko, Report Number 92-4, "Naval Propulsion Systems: An Evaluation of Alternative Technologies," Department of Ocean Engineering, M.I.T., October, 1992.

[21] Course Notes for M.I.T. Course 13.21, Ship Power and Propulsion, Fall Semester 1990.

[22] St John, L.G., "Analysis of Superconducting Machines for Naval Ship Propulsion," Thesis, Engineer, M.I.T., May 1978.

[23] Keenan, P.J., D.M. McGee, J.J. McGlothin, "Heavy Lift Ship Design Project," February 1993.

Appendix A. SMOKEY Source Code

```
'Smokey 1.0 was originally written in Microsoft Visual Basic 1.0 by J.J. McGlothin
'as part of a Masters Thesis in Electrical Engineering at MIT
'during the time period November 1992 to January 1993.
'During January 1993, the program was transferred to Visual Basic 2.0 to
'facilitate the addition of the graphing routines.
'Version 1.0 of this program was completed 16 January 1993. Additional effort
'is required to create online help if necessary.
'This program uses the graphing routine supplied with the Professional Version
'of Visual Basic 2.0, and therefore requires the following files (in addition
'to Windows and the executable file SMOKEY.EXE) to run:
'   GRAPH.VBX
'   GSW.EXE
'   GSWDLL.DLL
'These files, as well as the Visual Basic Run-Time Library file (VBRUN200.DLL)
'should be placed in the Microsoft Windows \SYSTEM subdirectory or
'the subdirectory where SMOKEY.EXE is located.


Global WepLoad As Single
Global PropLoad As Single
Global DCLoad As Single
Global VitLoad As Single
Global NVLoad As Single
Global TotLoad As Single
Global M As Integer
Global N As Integer
Global TotCap(1 To 10)  As Single
Global TotCost(1 To 10)  As Single
Global TotWt(1 To 10) As Single
Global NumGen(1 To 10) As Single
Global Prob(1 To 10) As Single
Global ProbReadout As String * 7


' Memory management functions for determining system information
' displayed in the About Dialog

' Returns the current system configurations flags
Declare Function GetWinFlags Lib "kernel" () As Long

' Returns the number of free bytes in the global heap
Declare Function GetFreeSpace Lib "kernel" (ByVal flag%) As Long

' System configuration flags
Global Const WF_CPU286 = &H2&
Global Const WF_CPU386 = &H4&
Global Const WF_CPU486 = &H8&
Global Const WF_STANDARD = &H10&
Global Const WF_ENHANCED = &H20&
Global Const WF_80x87 = &H400&
```

```
Begin Form Copyr
  BackColor      =  &H00C0C0C0&
  BorderStyle    =  0 'None
  Caption        =  "Smokey"
  ControlBox     =  0 'False
  Height         =  2745
  Icon           =  COPYR.FRX:0000
  Left           =  210
  LinkMode       =  1 'Source
  LinkTopic      =  "Form1"
  MaxButton      =  0 'False
  MinButton      =  0 'False
  ScaleHeight    =  2340
  ScaleWidth     =  4200
  Top            =  3150
  Width          =  4320
  Begin Timer Timer1
    Interval     =  2000
    Left         =  240
    Top          =  240
  End
  Begin Image Image2
    Height       =  480
    Left         =  3240
    Picture      =  COPYR.FRX:0302
    Top          =  1200
    Width        =  480
  End
  Begin Image Image1
    Height       =  480
    Left         =  480
    Picture      =  COPYR.FRX:0604
    Top          =  1200
    Width        =  480
  End
  Begin Label Label2
    BackColor    =  &H00C0C0C0&
    Caption      =  "J.J. McGlothin"
    Height       =  255
    Left         =  1440
    TabIndex     =  1
    Top          =  1560
    Width        =  1335
  End
  Begin Label Label1
    BackColor    =  &H00C0C0C0&
    Caption      =  "Copyright 1993"
    Height       =  255
    Left         =  1440
    TabIndex     =  0
    Top          =  1080
    Width        =  1335
  End
  Begin Label Label3
```

```
        BackColor      =   &H00C0C0C0&
        Caption        =   "Smokey  Version 1.0"
        FontBold       =   -1  'True
        FontItalic     =   0   'False
        FontName       =   "MS Sans Serif"
        FontSize       =   9.75
        FontStrikethru =   0   'False
        FontUnderline  =   -1  'True
        Height         =   495
        Left           =   1080
        TabIndex       =   2
        Top            =   360
        Width          =   2175
    End
End
'This form is the startup form which displays the program name and version and Copyright information.
'The form is displayed about 2 seconds, then starts the program by loading the load information form.

Sub Command1_Click ()
    M = 1
    LOADFRM.Show
    Unload Copyr
End Sub

Sub Timer1_Timer ()
    M = 1
    LOADFRM.Show
    Unload Copyr
End Sub
```

```
Begin Form Loadfrm
  Caption      =  "Load Information"
  Height       =  5910
  Icon         =  LOADFRM.FRX:0000
  Left         =  1440
  LinkMode     =  1 'Source
  LinkTopic    =  "Form3"
  MaxButton    =  0  'False
  ScaleHeight  =  5220
  ScaleWidth   =  4815
  Top          =  1095
  Width        =  4935
  Begin CommandButton Command1
    Caption    =  "OK"
    Default    =  -1 'True
    Height     =  615
    Left       =  1440
    TabIndex   =  6
    Top        =  4440
    Width      =  1935
  End
  Begin TextBox NVText
    Height     =  495
    Left       =  2040
    TabIndex   =  5
    Top        =  3720
    Width      =  1815
  End
  Begin TextBox VitText
    Height     =  495
    Left       =  2040
    TabIndex   =  4
    Top        =  3000
    Width      =  1815
  End
  Begin TextBox DCText
    Height     =  495
    Left       =  2040
    TabIndex   =  3
    Top        =  2280
    Width      =  1815
  End
  Begin TextBox PropText
    Height     =  495
    Left       =  2040
    TabIndex   =  2
    Top        =  1560
    Width      =  1815
  End
  Begin TextBox WepText
    Height     =  495
    Left       =  2040
    TabIndex   =  1
    Top        =  840
```

```
    Width       =  1815
End
Begin Label Label6
   Caption      =  "kw"
   Height       =  255
   Left         =  4080
   TabIndex     =  11
   Top          =  3840
   Width        =  375
End
Begin Label Label11
   Caption      =  "Non-Vital"
   Height       =  255
   Left         =  480
   TabIndex     =  16
   Top          =  3840
   Width        =  855
End
Begin Label Label5
   Caption      =  "kw"
   Height       =  255
   Left         =  4080
   TabIndex     =  10
   Top          =  3120
   Width        =  375
End
Begin Label Label10
   Caption      =  "Vital"
   Height       =  255
   Left         =  720
   TabIndex     =  15
   Top          =  3120
   Width        =  495
End
Begin Label Label4
   Caption      =  "kw"
   Height       =  255
   Left         =  4080
   TabIndex     =  9
   Top          =  2400
   Width        =  375
End
Begin Label Label9
   Caption      =  "Damage Control"
   Height       =  255
   Left         =  240
   TabIndex     =  14
   Top          =  2400
   Width        =  1455
End
Begin Label Label3
   Caption      =  "kw"
   Height       =  255
   Left         =  4080
```

```
      TabIndex    =  8
      Top         =  1680
      Width       =  375
   End
   Begin Label Label8
      Caption     =  "Propulsion"
      Height      =  255
      Left        =  480
      TabIndex    =  13
      Top         =  1680
      Width       =  975
   End
   Begin Label Label2
      Caption     =  "kw"
      Height      =  255
      Left        =  4080
      TabIndex    =  7
      Top         =  960
      Width       =  375
   End
   Begin Label Label7
      Caption     =  "Combat Systems"
      Height      =  255
      Left        =  240
      TabIndex    =  12
      Top         =  960
      Width       =  1455
   End
   Begin Label Label1
      Caption     =  "Input All Loads in KW"
      Height      =  255
      Left        =  1200
      TabIndex    =  0
      Top         =  240
      Width       =  1935
   End
   Begin Menu File
      Caption     =  "&File"
      Begin Menu Exit
         Caption     =  "E&xit"
      End
   End
   Begin Menu Help
      Caption     =  "&Help"
      Begin Menu About
         Caption     =  "&About"
      End
   End
End
'This form inputs the electrical load information.

Sub About_Click ()
   'Display the Information form.
   frmAbout.Show
```

```
End Sub

Sub Command1_Click ()
    'Read in the load in each catagory
    WepLoad = Val(WepText.Text)
    PropLoad = Val(PropText.Text)
    DCLoad = Val(DCText.Text)
    VitLoad = Val(VitText.Text)
    NVLoad = Val(NVText.Text)
    'Check for an invalid input, and display an error message if necessary.
    If WepLoad < 0 Then
        GoTo 10
    End If
    If PropLoad < 0 Then
        GoTo 10
    End If
    If DCLoad < 0 Then
        GoTo 10
    End If
    If VitLoad < 0 Then
        GoTo 10
    End If
    If NVLoad < 0 Then
        GoTo 10
    End If
    'Load the Index Selection form and unload this form.
    Indec.Show
    Unload loadfrm
    GoTo 11
10  Inerr.Show 1
11 End Sub

Sub Exit_Click ()
    'Exit the program.
    End
End Sub
```

```
Begin Form Indec
  BorderStyle   =  1 'Fixed Single
  Caption       =  "Select Index"
  Height        =  5265
  Icon          =  INDEC.FRX:0000
  Left          =  1905
  LinkTopic     =  "Form2"
  MaxButton     =  0 'False
  ScaleHeight   =  4575
  ScaleWidth    =  4335
  Top           =  1095
  Width         =  4455
  Begin CommandButton Command1
    Caption     =  "OK"
    Default     =  -1 'True
    Height      =  495
    Left        =  2520
    TabIndex    =  11
    Top         =  3600
    Width       =  1455
  End
  Begin TextBox Text8
    BorderStyle =  0 'None
    Height      =  855
    Left        =  480
    MultiLine   =  -1 'True
    TabIndex    =  10
    Text        =  "Note:  Vital Loads are automatically included in the total."
    Top         =  3480
    Width       =  1575
  End
  Begin TextBox Text7
    BorderStyle =  0 'None
    Height      =  255
    Left        =  120
    TabIndex    =  9
    Text        =  "Damage Control"
    Top         =  2880
    Width       =  1575
  End
  Begin TextBox Text6
    BorderStyle =  0 'None
    Height      =  255
    Left        =  120
    TabIndex    =  8
    Text        =  "Propulsion"
    Top         =  2040
    Width       =  1575
  End
  Begin TextBox Text5
    BorderStyle =  0 'None
    Height      =  255
    Left        =  120
    TabIndex    =  7
```

```
   Text       =   "Combat Systems"
   Top        =   1200
   Width      =   1575
End
Begin TextBox DCReadout
   Height     =   285
   Left       =   1920
   TabIndex   =   6
   Top        =   2760
   Width      =   2055
End
Begin HScrollBar DCFrac
   Height       =   255
   LargeChange  =   10
   Left         =   1920
   Max          =   100
   TabIndex     =   5
   Top          =   3000
   Width        =   2055
End
Begin TextBox PropReadout
   Height     =   285
   Left       =   1920
   TabIndex   =   4
   Top        =   1920
   Width      =   2055
End
Begin HScrollBar PropFrac
   Height       =   255
   LargeChange  =   10
   Left         =   1920
   Max          =   100
   TabIndex     =   3
   Top          =   2160
   Width        =   2055
End
Begin TextBox WepReadout
   Height     =   285
   Left       =   1920
   TabIndex   =   2
   Top        =   1080
   Width      =   2055
End
Begin HScrollBar WepFrac
   Height       =   255
   LargeChange  =   10
   Left         =   1920
   Max          =   100
   TabIndex     =   1
   Top          =   1320
   Width        =   2055
End
Begin TextBox Text1
   BorderStyle  =   0  'None
```

```
      Enabled      =  0  'False
      Height       =  735
      Left         =  120
      MultiLine    =  -1 'True
      TabIndex     =  0
      Text         =  "This program will compute the probability that the configuration input will be able
to supply the selected percentages of the total load:"
      Top          =  120
      Width        =  4095
   End
   Begin Menu File
      Caption      =  "&File"
      Begin Menu Exit
         Caption      =  "E&xit"
      End
   End
   Begin Menu Help
      Caption      =  "&Help"
      Begin Menu About
         Caption      =  "&About"
      End
   End
End
'This form allows the user to select the desired reliability index.

Sub About_Click ()
   'Display the information form.
   frmAbout.Show
End Sub

Sub Command1_Click ()
   'Compute the total load.
   TempLoad = (WepFrac.Value * WepLoad + PropFrac.Value * PropLoad + DCFrac.Value * DCLoad)
   TotLoad = TempLoad / 100 + VitLoad
   N = 1
   'Display the Generator Input form and unload this form.
   Genfrm.Show
   Unload Indec
End Sub

Sub DCFrac_Change ()
   'Select and display the percentage of Damage Control load to be included in the total load.
   DCReadout.Text = Format$(DCFrac.Value)
End Sub

Sub Exit_Click ()
   'Exit the program.
   End
End Sub

Sub PropFrac_Change ()
   'Select and display the percentage of propulsion load to be included in the total load.
   PropReadout.Text = Format$(PropFrac.Value)
End Sub
```

83

```
Sub WepFrac_Change ()
    'Select and display the percentage of combat systems load to be included in the total load.
    WepReadout.Text = Format$(WepFrac.Value)
End Sub
```

```
Begin Form Genfrm
  BorderStyle    =  1  'Fixed Single
  Caption        =  "Generator Information"
  Height         =  7035
  Icon           =  GEN.FRX:0000
  Left           =  2025
  LinkMode       =  1  'Source
  LinkTopic      =  "Form1"
  MaxButton      =  0  'False
  ScaleHeight    =  6345
  ScaleWidth     =  4665
  Top            =  60
  Width          =  4785
  Begin CommandButton Command5
    Caption      =  "Next Config"
    Height       =  615
    Left         =  3240
    TabIndex     =  19
    Top          =  3720
    Width        =  1335
  End
  Begin CommandButton Command4
    Caption      =  "Graphs"
    Height       =  615
    Left         =  720
    TabIndex     =  18
    Top          =  5640
    Width        =  3255
  End
  Begin TextBox ProbReadout
    Height       =  375
    Left         =  1440
    TabIndex     =  17
    Top          =  5160
    Width        =  1815
  End
  Begin TextBox Text1
    BorderStyle  =  0  'None
    Height       =  495
    Left         =  240
    MultiLine    =  -1 'True
    TabIndex     =  16
    Text         =  "The probability that the configuration will be able to supply the loads at any random
time is"
    Top          =  4560
    Width        =  4095
  End
  Begin CommandButton Command3
    Caption      =  "Finished"
    Height       =  615
    Left         =  1680
    TabIndex     =  15
    Top          =  3720
    Width        =  1335
```

```
End
Begin CommandButton Command1
  Caption      =  "Input"
  Default      =  -1  'True
  Height       =  615
  Left         =  120
  TabIndex     =  14
  Top          =  3720
  Width        =  1335
End
Begin TextBox CostText
  Height       =  375
  Left         =  1800
  TabIndex     =  9
  Top          =  3120
  Width        =  1095
End
Begin TextBox WtText
  Height       =  375
  Left         =  1800
  TabIndex     =  8
  Top          =  2400
  Width        =  1095
End
Begin TextBox RelText
  Height       =  375
  Left         =  1800
  TabIndex     =  7
  Top          =  1680
  Width        =  1095
End
Begin TextBox CapText
  Height       =  375
  Left         =  1800
  TabIndex     =  6
  Top          =  960
  Width        =  1095
End
Begin TextBox NText
  Enabled      =  0  'False
  Height       =  615
  Left         =  2760
  TabIndex     =  1
  Top          =  120
  Width        =  735
End
Begin Label Label9
  Caption      =  "$"
  Height       =  255
  Left         =  3120
  TabIndex     =  13
  Top          =  3240
  Width        =  735
End
```

```
Begin Label Label5
  Caption      = "Cost"
  Height       = 375
  Left         = 240
  TabIndex     = 5
  Top          = 3120
  Width        = 1215
End
Begin Label Label8
  Caption      = "LTons"
  Height       = 255
  Left         = 3000
  TabIndex     = 12
  Top          = 2520
  Width        = 855
End
Begin Label Label4
  Caption      = "Weight"
  Height       = 375
  Left         = 240
  TabIndex     = 4
  Top          = 2400
  Width        = 1215
End
Begin Label Label7
  Caption      = "0-1.0"
  Height       = 255
  Left         = 3000
  TabIndex     = 11
  Top          = 1800
  Width        = 855
End
Begin Label Label3
  Caption      = "Reliability"
  Height       = 375
  Left         = 240
  TabIndex     = 3
  Top          = 1680
  Width        = 1215
End
Begin Label Label6
  Caption      = "KW"
  Height       = 255
  Left         = 3000
  TabIndex     = 10
  Top          = 1080
  Width        = 855
End
Begin Label Label2
  Caption      = "Capacity"
  Height       = 375
  Left         = 240
  TabIndex     = 2
  Top          = 960
```

```
      Width        =  1215
   End
   Begin Label Label1
      Caption      =  "Generator Number"
      Height       =  255
      Left         =  480
      TabIndex     =  0
      Top          =  240
      Width        =  1695
   End
   Begin Menu File
      Caption      =  "&File"
      Begin Menu Exit
         Caption      =  "E&xit"
      End
   End
   Begin Menu Help
      Caption      =  "&Help"
      Begin Menu About
         Caption      =  "&About"
      End
   End
End
'This form receives information about each generator, then computes the
'desired reliability index.


      Dim Cap(0 To 12) As Single
      Dim Rel(0 To 12) As Single
      Dim Avail(0 To 12) As Single
      Dim Wt(1 To 12) As Single
      Dim Cost(1 To 12) As Single
      Dim CapTable() As Single
      Dim ProbTable() As Single

Sub About_Click ()
   'Display the information form.
   frmAbout.Show
End Sub

Sub CapText_Change ()
   NText.Text = Format$(N)
End Sub

Sub Command1_Click ()
   'This subroutine reads the capacity, reliability, cost, and weight of each generator.

   Cap(N) = Val(CapText.Text)
   Rel(N) = Val(RelText.Text)
   Avail(N) = 1 - Rel(N)
   'Note: Avail(N) is actually Unavailability.

   Wt(N) = Val(WtText.Text)
   Cost(N) = Val(CostText.Text)
```

88

```
'Display an error message if any parameter input is invalid.

If Cap(N) <= 0# Then GoTo 12

If Rel(N) > 1# Then GoTo 12

If Rel(N) <= 0# Then GoTo 12

If Wt(N) < 0# Then GoTo 12
'Display the information.
CapText.Text = Format$(Cap(N))
RelText.Text = Format$(Rel(N))
WtText.Text = Format$(Wt(N))
CostText.Text = Format$(Cost(N))
'Increment N by 1 to get ready for the next generator.
N = N + 1
If N = 13 Then
   'Display an error message if the max number of generators per configuration (12) is exceeded.
   Generr.Show
End If
NText.Text = Format$(N)
GoTo 13
12 Inerr.Show

13 End Sub

Sub Command3_Click ()
   'This subroutine calculates the reliability index for the configuration input.
   Dim i As Integer
   Dim J As Integer
   Dim K As Integer
   Dim L As Integer
   Dim IR As Integer
   Dim Start As Integer
   Dim StopLoop As Integer
   Dim StopIt As Integer
   Dim CapSum As Single
   Dim CostSum As Single
   Dim WtSum As Single
   'Subtract 1 from the number of generators since 1 was added at the end of the input subroutine.
   N = N - 1
   'Calculate the total capacity, cost, and weight of the configuration input.
   Dim Uplimit As Integer
   Uplimit = (2 ^ N) - 1
   ReDim CapTable(0 To Uplimit) As Single
   ReDim ProbTable(0 To Uplimit) As Single
   For i = 1 To N Step 1
      CapSum = CapSum + Cap(i)
      CostSum = CostSum + Cost(i)
      WtSum = WtSum + Wt(i)
   Next i
   'Display an error message if you don't have enough capacity.
   If TotLoad > CapSum Then Error2.Show 1
```

```
    'Store the configuration totals into an array. The subscript M is incremented for each configuration
input.
    TotCap(M) = CapSum
    NumGen(M) = N
    TotCost(M) = CostSum
    TotWt(M) = WtSum
    'Compute the capacity outage probability table for the current configuration.
    CapTable(0) = 0#
    ProbTable(0) = 1#
    For i = 1 To N
        Start = (2 ^ (i - 1))
        StopLoop = ((2 ^ i) - 1)
        K = 0
        For J = Start To StopLoop Step 1
            CapTable(J) = Cap(i) + CapTable(K)
            ProbTable(J) = ProbTable(K) * Rel(i)
            K = K + 1
        Next J
        StopIt = (2 ^ (i - 1)) - 1
        For L = 0 To StopIt Step 1
            ProbTable(L) = ProbTable(L) * Avail(i)
        Next L
    Next i

300 'Compare the total load to the table to determine the reliability index.
    StopLoop = (2 ^ N) - 1
    Prob(M) = 0#
    For i = 0 To StopLoop Step 1
        If TotLoad > CapTable(i) Then
            Prob(M) = Prob(M)
        ElseIf TotLoad <= CapTable(i) Then
            Prob(M) = Prob(M) + ProbTable(i)
        End If
    Next i
    'Display the index
    ProbReadout.Text = Format$(Prob(M))
End Sub

Sub Command4_Click ()
    'Display scatter graphs of all configurations input.
    CapGraph.CapGraph.NumPoints = M
    CapGraph.CapGraph.AutoInc = 1
    For i = 1 To M
        CapGraph.CapGraph.XPosData = TotCap(i)
    Next i
    For i = 1 To M
        CapGraph.CapGraph.GraphData = Prob(i)
    Next i
    CapGraph.Show
    NumGenGraph.NumGenGraph.NumPoints = M
    NumGenGraph.NumGenGraph.AutoInc = 1
    For i = 1 To M
        NumGenGraph.NumGenGraph.XPosData = NumGen(i)
    Next i
```

```
    For i = 1 To M
       NumGenGraph.NumGenGraph.GraphData = Prob(i)
    Next i
    NumGenGraph.Show
    TotCostGraph.TotCostGraph.NumPoints = M
    TotCostGraph.TotCostGraph.AutoInc = 1
    For i = 1 To M
       TotCostGraph.TotCostGraph.XPosData = TotCost(i)
    Next i
    For i = 1 To M
       TotCostGraph.TotCostGraph.GraphData = Prob(i)
    Next i
    TotCostGraph.Show
    TotWeightGraph.TotWeightGraph.NumPoints = M
    TotWeightGraph.TotWeightGraph.AutoInc = 1
    For i = 1 To M
       TotWeightGraph.TotWeightGraph.XPosData = TotWt(i)
    Next i
    For i = 1 To M
       TotWeightGraph.TotWeightGraph.GraphData = Prob(i)
    Next i
    TotWeightGraph.Show
    Unload Genfrm
End Sub

Sub Command5_Click ()
    'Increment M and reset N to allow another configuration to be input.
    M = M + 1
    N = 1
    NText.Text = Format$(N)
End Sub

Sub Exit_Click ()
    'Exit the program
    End
End Sub

Sub Text2_Change ()
    NText.Text = Format$(N)
End Sub

Sub Text3_Change ()
    NText.Text = Format$(N)
End Sub

Sub Text4_Change ()
    NText.Text = Format$(N)
End Sub

Sub Text5_Change ()
    NText.Text = Format$(N)
End Sub
```

```
Begin Form CapGraph
  AutoRedraw    = -1 'True
  BorderStyle   = 1 'Fixed Single
  Caption       = "Capacity"
  Height        = 5565
  Icon          = CAPGRAPH.FRX:0000
  Left          = 60
  LinkTopic     = "Form1"
  MaxButton     = 0 'False
  ScaleHeight   = 4875
  ScaleWidth    = 7365
  Top           = 555
  Width         = 7485
  Begin GRAPH CapGraph
    BottomTitle   = "Total Installed Capacity"
    ColorData     = CAPGRAPH.FRX:0302
    DrawMode      = 3 'Blit
    ExtraData     = CAPGRAPH.FRX:0304
    FontFamily    = CAPGRAPH.FRX:0306
    FontSize      = CAPGRAPH.FRX:030A
    FontStyle     = CAPGRAPH.FRX:0314
    GraphCaption  = "Index vs Total Installed Capacity"
    GraphData     = CAPGRAPH.FRX:0318
    GraphType     = 9 'Scatter
    Height        = 4695
    LabelText     = CAPGRAPH.FRX:032C
    Left          = 120
    LeftTitle     = "Index"
    LegendText    = CAPGRAPH.FRX:032E
    PatternData   = CAPGRAPH.FRX:0330
    RandomData    = 0 'Off
    SymbolData    = CAPGRAPH.FRX:0332
    TabIndex      = 0
    Top           = 120
    Width         = 7095
    XPosData      = CAPGRAPH.FRX:0336
    YAxisMax      = 1
    YAxisMin      = 0.5
    YAxisStyle    = 2 'User-defined
    YAxisTicks    = 5
  End
  Begin Menu File
    Caption       = "&File"
    Begin Menu Print
      Caption       = "&Print"
    End
    Begin Menu Exit
      Caption       = "E&xit"
    End
  End
  Begin Menu Help
    Caption       = "&Help"
    Begin Menu About
      Caption       = "&About"
```

92

```
        End
      End
End
 'This form displays a scatter graph of the chosen index as a function of the total installed capacity

Sub About_Click ()
   'Display the information form
   frmAbout.Show
End Sub

Sub Exit_Click ()
   'Exit the program
   End
End Sub

Sub Print_Click ()
   'Send this graph to the printer
   PrintForm
End Sub
```

```
Begin Form NumGenGraph
  AutoRedraw    = -1 'True
  BorderStyle   = 1 'Fixed Single
  Caption       = "Number of Generators"
  Height        = 5565
  Icon          = NUMGENGR.FRX:0000
  Left          = 150
  LinkTopic     = "Form1"
  MaxButton     = 0 'False
  ScaleHeight   = 4875
  ScaleWidth    = 7365
  Top           = 915
  Width         = 7485
  Begin GRAPH NumGenGraph
    BottomTitle   = "Total Number of Generators"
    ColorData     = NUMGENGR.FRX:0302
    DrawMode      = 3 'Blit
    ExtraData     = NUMGENGR.FRX:0304
    FontFamily    = NUMGENGR.FRX:0306
    FontSize      = NUMGENGR.FRX:030A
    FontStyle     = NUMGENGR.FRX:0314
    GraphCaption  = "Index vs Total Number of Generators"
    GraphData     = NUMGENGR.FRX:0318
    GraphType     = 9 'Scatter
    Height        = 4695
    LabelText     = NUMGENGR.FRX:031C
    Left          = 120
    LeftTitle     = "Index"
    LegendText    = NUMGENGR.FRX:031E
    PatternData   = NUMGENGR.FRX:0320
    RandomData    = 0 'Off
    SymbolData    = NUMGENGR.FRX:0322
    TabIndex      = 0
    Top           = 120
    Width         = 7095
    XPosData      = NUMGENGR.FRX:0324
    YAxisMax      = 1
    YAxisMin      = 0.5
    YAxisStyle    = 2 'User-defined
    YAxisTicks    = 5
  End
  Begin Menu File
    Caption       = "&File"
    Begin Menu Print
      Caption       = "&Print"
    End
    Begin Menu Exit
      Caption       = "E&xit"
    End
  End
  Begin Menu Help
    Caption       = "&Help"
    Begin Menu About
      Caption       = "&About"
```

```
        End
      End
    End
'This form displays a scatter graph of the selected reliability index vs the total number of generators.

Sub About_Click ()
    'Display the Information form.
    frmAbout.Show
End Sub

Sub Exit_Click ()
    'Exit the program.
    End
End Sub

Sub Print_Click ()
    'Send this graph to the printer.
    PrintForm
End Sub
```

```
Begin Form TotCostGraph
  AutoRedraw    = -1 'True
  BorderStyle   = 1 'Fixed Single
  Caption       = "Cost"
  Height        = 5565
  Icon          = TOTCOSTG.FRX:0000
  Left          = 240
  LinkTopic     = "Form1"
  MaxButton     = 0 'False
  ScaleHeight   = 4875
  ScaleWidth    = 7365
  Top           = 1260
  Width         = 7485
  Begin GRAPH TotCostGraph
    BottomTitle   = "Total Cost"
    ColorData     = TOTCOSTG.FRX:0302
    DrawMode      = 3 'Blit
    ExtraData     = TOTCOSTG.FRX:0304
    FontFamily    = TOTCOSTG.FRX:0306
    FontSize      = TOTCOSTG.FRX:030A
    FontStyle     = TOTCOSTG.FRX:0314
    GraphCaption  = "Index vs Total Cost"
    GraphData     = TOTCOSTG.FRX:0318
    GraphType     = 9 'Scatter
    Height        = 4695
    LabelText     = TOTCOSTG.FRX:031C
    Left          = 120
    LeftTitle     = "Index"
    LegendText    = TOTCOSTG.FRX:031E
    PatternData   = TOTCOSTG.FRX:0320
    RandomData    = 0 'Off
    SymbolData    = TOTCOSTG.FRX:0322
    TabIndex      = 0
    Top           = 120
    Width         = 7095
    XPosData      = TOTCOSTG.FRX:0324
    YAxisMax      = 1
    YAxisMin      = 0.5
    YAxisStyle    = 2 'User-defined
    YAxisTicks    = 5
  End
  Begin Menu File
    Caption       = "&File"
    Begin Menu Print
      Caption       = "&Print"
    End
    Begin Menu Exit
      Caption       = "E&xit"
    End
  End
  Begin Menu Help
    Caption       = "&Help"
    Begin Menu About
      Caption       = "&About"
```

```
        End
      End
    End
'This form displays a scatter graph of the selected reliability index vs the total cost of the generators.

Sub About_Click ()
    'Display the Information form.
    frmAbout.Show
End Sub

Sub Exit_Click ()
    'Exit the program.
    End
End Sub

Sub Print_Click ()
    'Send this graph to the printer.
    PrintForm
End Sub
```

```
Begin Form TotWeightGraph
  AutoRedraw      = -1 'True
  BorderStyle     = 1 'Fixed Single
  Caption         = "Weight"
  Height          = 5565
  Icon            = TOTWEIGH.FRX:0000
  Left            = 315
  LinkTopic       = "Form2"
  MaxButton       = 0 'False
  ScaleHeight     = 4875
  ScaleWidth      = 7365
  Top             = 1620
  Width           = 7485
  Begin GRAPH TotWeightGraph
    BottomTitle   = "Total Weight"
    ColorData     = TOTWEIGH.FRX:0302
    DrawMode      = 3 'Blit
    ExtraData     = TOTWEIGH.FRX:0304
    FontFamily    = TOTWEIGH.FRX:0306
    FontSize      = TOTWEIGH.FRX:030A
    FontStyle     = TOTWEIGH.FRX:0314
    GraphCaption  = "Index vs Total Weight"
    GraphData     = TOTWEIGH.FRX:0318
    GraphType     = 9 'Scatter
    Height        = 4695
    LabelText     = TOTWEIGH.FRX:031C
    Left          = 120
    LeftTitle     = "Index"
    LegendText    = TOTWEIGH.FRX:031E
    PatternData   = TOTWEIGH.FRX:0320
    RandomData    = 0 'Off
    SymbolData    = TOTWEIGH.FRX:0322
    TabIndex      = 0
    Top           = 120
    Width         = 7095
    XPosData      = TOTWEIGH.FRX:0324
    YAxisMax      = 1
    YAxisMin      = 0.5
    YAxisStyle    = 2 'User-defined
    YAxisTicks    = 5
  End
  Begin Menu File
    Caption       = "&File"
    Begin Menu Print
      Caption     = "&Print"
    End
    Begin Menu Exit
      Caption     = "E&xit"
    End
  End
  Begin Menu Help
    Caption       = "&Help"
    Begin Menu About
      Caption     = "&About"
```

```
        End
      End
    End
'This form displays a scatter graph of the selected reliability index vs the total weight of the generators.

Sub About_Click ()
    'Display the Information form.
    frmAbout.Show
End Sub

Sub Exit_Click ()
    'Exit the program.
    End
End Sub

Sub Print_Click ()
    'Send this graph to the printer.
    PrintForm
End Sub
```

```
Begin Form frmAbout
  BorderStyle    =  3 'Fixed Double
  Caption        =  "About Smokey"
  ControlBox     =  0 'False
  Height         =  2520
  Icon           =  ABOUT.FRX:0000
  Left           =  915
  LinkTopic      =  "Form1"
  MaxButton      =  0 'False
  MinButton      =  0 'False
  ScaleHeight    =  2115
  ScaleWidth     =  5130
  Top            =  1080
  Width          =  5250
  Begin CommandButton Command1
    Cancel       =  -1 'True
    Caption      =  "OK"
    Default      =  -1 'True
    Height       =  330
    Left         =  4080
    TabIndex     =  0
    Top          =  225
    Width        =  930
  End
  Begin Label lblCoProcessorInfo
    Height       =  195
    Left         =  3165
    TabIndex     =  6
    Top          =  1815
    Width        =  1695
  End
  Begin Label lblModeInfo
    Height       =  195
    Left         =  885
    TabIndex     =  5
    Top          =  1350
    Width        =  2280
  End
  Begin Label lblMemoryInfo
    Height       =  195
    Left         =  3165
    TabIndex     =  4
    Top          =  1605
    Width        =  1725
  End
  Begin Line Line1
    BorderWidth  =  2
    X1           =  900
    X2           =  4725
    Y1           =  1230
    Y2           =  1230
  End
  Begin Label Label3
    AutoSize     =  -1 'True
```

```
        Caption      =  "Math Co-Processor:"
        Height       =  195
        Left         =  900
        TabIndex     =  3
        Top          =  1815
        Width        =  1680
     End
     Begin Label Label2
        AutoSize     =  -1  'True
        Caption      =  "Memory:"
        Height       =  195
        Left         =  900
        TabIndex     =  2
        Top          =  1575
        Width        =  720
     End
     Begin Label Label1
        AutoSize     =  -1  'True
        Caption      =  "Smokey  Version 1.0"
        Height       =  195
        Left         =  900
        TabIndex     =  1
        Top          =  225
        Width        =  1755
     End
     Begin Image Image1
        Height       =  480
        Left         =  165
        Picture      =  ABOUT.FRX:0302
        Top          =  225
        Width        =  480
     End
End
'This form displays information about the system and the version of Smokey that is running

Sub Command1_Click ()
  Unload Me
End Sub

Sub Form_Load ()
Dim WinFlags As Long

  ' Center form
  Left = Screen.Width / 2 - Width / 2
  Top = Screen.Height / 2 - Height / 2

  ' Retrieve current Windows system and memory configuration
  WinFlags = GetWinFlags()

  ' Display mode information
  If WinFlags And WF_ENHANCED Then
     lblModeInfo = "386 Enhanced Mode"
  Else
     lblModeInfo = "Standard Mode"
```

```
End If

' Display math co-processor information
If WinFlags And WF_80x87 Then
    lblCoProcessorInfo = "Present"
Else
    lblCoProcessorInfo = "Not Present"
End If

' Scan global heap to get memory information
temp = GetFreeSpace(0)
If Sgn(temp) = -1 Then
    FreeSpace = CLng(temp + 1&) Xor &HFFFFFFFF
Else
    FreeSpace = temp
End If

' Divide by 1024 to display info in KB
FreeSpace = FreeSpace / 1024
lblMemoryInfo = Format(FreeSpace, "#,#") + " KB Free"

End Sub
```

```
Begin Form Inerr
  BackColor      =  &H0000FFFF&
  BorderStyle    =  3 'Fixed Double
  Caption        =  "Error"
  ControlBox     =  0 'False
  Height         =  2895
  Left           =  1035
  LinkMode       =  1 'Source
  LinkTopic      =  "Form2"
  MaxButton      =  0 'False
  MinButton      =  0 'False
  ScaleHeight    =  2490
  ScaleWidth     =  4170
  Top            =  1140
  Width          =  4290
  Begin CommandButton Command1
    BackColor      =  &H00C0C0C0&
    Caption        =  "Try Again"
    Default        =  -1 'True
    Height         =  615
    Left           =  360
    TabIndex       =  1
    Top            =  1440
    Width          =  3495
  End
  Begin Label Label1
    BackColor      =  &H0000FFFF&
    Caption        =  "Improper Input Value!"
    Height         =  255
    Left           =  1080
    TabIndex       =  0
    Top            =  720
    Width          =  1935
  End
End
'This form is displayed whenever an improper value (eg reliability > 1) is input.

Sub Command1_Click ()
  'Return to the form where the improper value was input.
  Unload Inerr
End Sub
```

```
Begin Form Generr
  BackColor     =  &H0000FFFF&
  BorderStyle   =  1 'Fixed Single
  Caption       =  "Generator Error"
  ControlBox    =  0 'False
  Height        =  3105
  Left          =  1035
  LinkMode      =  1 'Source
  LinkTopic     =  "Form2"
  MaxButton     =  0 'False
  MinButton     =  0 'False
  ScaleHeight   =  2700
  ScaleWidth    =  3555
  Top           =  1140
  Width         =  3675
  Begin CommandButton Command1
    Caption     =  "OK"
    Default     =  -1 'True
    Height      =  615
    Left        =  840
    TabIndex    =  1
    Top         =  1680
    Width       =  1935
  End
  Begin Label Label1
    BackColor   =  &H0000FFFF&
    Caption     =  "You've entered the Maximum Number of Generators Allowable.  You must
""Finish"" or ""Quit"" here."
    Height      =  855
    Left        =  360
    TabIndex    =  0
    Top         =  240
    Width       =  2895
  End
End
'This form is displayed whenever the total number of generators allowable per configuration (12) is
exceeded.

Sub Command1_Click ()
  'Return to the generator input form
  Unload Generr
End Sub
```

```
Begin Form Error2
  BackColor    = &H00008000&
  BorderStyle  = 3 'Fixed Double
  Caption      = "Error"
  ControlBox   = 0 'False
  Height       = 2850
  Left         = 1035
  LinkMode     = 1 'Source
  LinkTopic    = "Form3"
  MaxButton    = 0 'False
  MinButton    = 0 'False
  ScaleHeight  = 2445
  ScaleWidth   = 3765
  Top          = 1140
  Width        = 3885
  Begin CommandButton Command1
    Caption      = "OK"
    Default      = -1 'True
    Height       = 735
    Left         = 840
    TabIndex     = 1
    Top          = 1320
    Width        = 2055
  End
  Begin Label Label1
    BackColor    = &H00008000&
    Caption      = "Load Exceeds Total System Capacity.  Add Another Generator or Quit."
    Height       = 735
    Left         = 240
    TabIndex     = 0
    Top          = 240
    Width        = 3255
  End
End
'This form is displayed whenever the total load exceeds the total installed capacity

Sub Command1_Click ()
  'Return to the Generator input form.
  Unload Error2
End Sub
```

Appendix B. TIGER Output Files

Case 1: 1 of 2 Identical Gas Turbine Generators Required On Line

```
*************************************************************************
*************************************************************************
**** TIGER SIMULATION FOR RELIABILITY, MAINTAINABILITY, AND AVAILABILITY ****
*************************************************************************
*************************************************************************
SIMPLIFIED ELECTRICAL GENERATION SYSTEM (2 GTG'S)

        ++++++++++++++++++++ TIGER 8.21 ++++++++++++++++++++
        +++++ NAVSEA 05MR  WASHINGTON, DC 20362-5101 +++++
        ++++++++++++++++++++ (202) 692-2150 ++++++++++++++++++++
```

INTIGER

RANDOM SEED IS   .0106203800
 250   0 .00 1.28 1357   1
TIMELINE   PAGE

TIMELINE SEQUENCE	PHASE TYPE	DURATION HOURS	CUMULATIVE HOURS	CUMULATIVE DAYS
1	1	720.00	720.00	30.00

TIMELINE SUMMARY BY PHASE

PHASE TYPE	HOURS	DAYS	PERCENT
1	720.00	30.00	100.00
TOTAL	720.00	30.00	100.00%

REPORT SELECTIONS

OPTION	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
4	1	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1

SIMULATION DIMENSIONAL LIMITS (STANDARD TIGER OR TIGER READER)

MAXCTL	MAXEGR	MAXEXP	MAXGRP	MAXID	MAXLOC	MAXLNK	MAXLNX	MAXMBR
1000	20	50	1000	19	3	3000	1000	5000

MAXNEQ	MAXPH	MAXQUE	MAXRUL	MAXRUN	MAXSEQ	MAXSHP	MAXSTK	MAXSUB
500	6	50	1000	9999	100	21	100	31

MAXTYP	LUIN	LUOUT
200	5	6

PHASE REPAIR

        PHASE: 1
             0
REPAIR ALLOWED: YES
EQPT TURNED ON: YES

MULTIPLIERS		SHOP	INVENTORY	MGMT	SPECIAL
MTBF	MTTR	CAPACITY	DELAY	TRIGGER	SHOPS
1.00	1.00	500	.00	.00	0

INTYPES   PAGE

TYPE NOMENCLATURE	MTBF	MTTR	DC	ADT1	ADT2	ADT3	SHOP	PRI	SWB
1 GAS GENERATOR	9300.0	9999.00	1.000	.0	.0	.0	GENL	0	
2 POWER TURBINE	50000.0	9999.00	1.000	.0	.0	.0	GENL	0	
3 SHIP REP COMP	3000.0	13.00	1.000	.0	.0	.0	GENL	0	
4 SS GENERATOR	25000.0	6.00	1.000	.0	.0	.0	GENL	0	
5 SW CIRC PUMP	3000.0	8.00	1.000	.0	.0	.0	GENL	0	
6 CONTROL PANEL	5000.0	1.90	1.000	.0	.0	.0	GENL	0	
7 DAU	25000.0	1.00	1.000	.0	.0	.0	GENL	0	

INEQUIP   PAGE

TYPE	EQUIPMENT ASSIGNED	
1	1	2
2	4	5
3	7	8
4	10	11
5	13	14
6	16	17
7	19	20

INSPARES   PAGE

SPARES TYPE	ORG	INTER	DEPOT	FACTOR
ALL EQUIPMENT TYPES HAVE UNLIMITED SPARES
INCONFIG   PAGE

MISSION WILL BE RUN WITH 1 PHASE TYPES IN VARIABLE SEQUENCE.

```
ELEC   1   1   505
GT GEN        503   .00
 7 506   1   4   7  10  13  16  19
 7 507   2   5   8  11  14  17  20
 2 505 506 507
STRING RULE   1 506
STRING RULE   4 506
STRING RULE   7 506
STRING RULE  10 506
STRING RULE  13 506
STRING RULE  16 506
STRING RULE  19 506
STRING RULE   2 507
STRING RULE   5 507
STRING RULE   8 507
STRING RULE  11 507
STRING RULE  14 507
STRING RULE  17 507
STRING RULE  20 507
STRING RULE 506 507
```

INPUT DATA HIGH VALUES

DURATION	TYPES	GROUPS	EQUIPS	PH-SEQ	PH-TYP	TRIALS
720.00	7	507	20	1	1	250
OUTTIGER		PAGE				

RELIABILITY FOR PHASE 1, 1   .236   RELIABILITY THRU PHASE 1   .236
AVERAGE AVAILABILITY   AVG. AVAIL. THRU PHASE 1   .907
        FOR PHASE 1, 1   .907   TIME (END OF PHASE)   720.000
INSTANT AVAILABILITY   INSTANT AVAILABILITY
        AT BEGINNING OF PHASE 1.000   AT END OF PHASE   .828
FINAL SUMMARY STATS   PAGE

SYSTEM FIGURES OF MERIT AFTER

250 MISSION TRIALS	MEAN	STANDARD DEVIATION OF THE SAMPLE MEAN
AT END OF MISSION:		
RELIABILITY	.236	.027
RELIABILITY LOWER PRECISION LIMIT		
(BASED ON STANDARD DEVIATION CRITERIA)	.202	
INSTANTANEOUS AVAILABILITY	.828	.024
AVERAGE AVAILABILITY	.907	.013
ESTIMATES OF LONG-TERM VALUES:		
MEAN TIME BETWEEN FAILURES	497.9	
MEAN TIME TO REPAIR	55.2	
AVAILABILITY	.900	
MISSION PERFORMANCE (FAILURE & REPAIR INFORMATION		
CALCULATED FROM TIGER SIMULATION DATA):		
MEAN UP TIME	538.9	9.443
MEAN DOWN TIME	55.2	9.443
MEAN REPAIR TIME	8.2	.655
MEAN ACTIVE REPAIR TIME	8.2	.655
MEAN TIME TO FIRST FAILURE	520.6	20.546

TOTAL NO. OF SYSTEM FAILURES = 303

OUTRA   PAGE

SUBSYSTEM	PHASE SEQ	TYPE	TIME	RELIABILITY IN PHASE	THRU	AVERAGE AVAILABILITY IN PHASE	THRU	INSTANT AVAILABILITY BEGIN	END
GT GEN	1	1	720.0	1.000	1.000	1.000	1.000	1.000	1.000

TABLE FAILURES NUM   PAGE

EQUIP FAILURE SUMMARY BY EQUIPMENT NUMBER

EQUIP. NO.	TYPE NO.	TOTAL EQUIP. FAILURES	AVG. NO. FAILURES PER MISSION	FGC/EIC
1	1	21	.084	
2	1	16	.064	
4	2	1	.004	
5	2	3	.012	
7	3	56	.224	
8	3	56	.224	
10	4	6	.024	
11	4	6	.024	
13	5	40	.160	
14	5	52	.208	
16	6	29	.116	
17	6	17	.068	
19	7	5	.020	
20	7	4	.016	
		312	1.248	

TABLE FAILURES TYPE   PAGE

EQUIP FAILURE SUMMARY BY EQUIPMENT TYPE NUMBER

TYPE	TOTAL EQUIP. FAILURES	AVG. NO. FAILURES PER MISSION	MAINTENANCE HOURS	STD. DEV. MAINT. HRS	FGC/EIC
1	37	.148	.000	.000	
2	4	.016	.000	.000	
3	112	.448	1420.410	1.653	
4	12	.048	43.682	.912	
5	92	.368	716.970	.842	
6	46	.184	82.216	.223	
7	9	.036	11.858	.521	
	312	1.248	27.220		

UNLIMITED SPARES
SUMMARY OF SPARES USED

SPARE TYPE	ORGANIZATION SPARES			INTERMEDIATE SPARES			DEPOT SPARES		
	TOTAL STOCK	USED	USE PER MISSION	TOTAL STOCK	USED	USE PER MISSION	TOTAL STOCK	USED	USE PER MISSION
1	90000	0	.000	90000	0	.000	90000	0	.000
2	90000	0	.000	90000	0	.000	90000	0	.000
3	90000	112	.448	90000	0	.000	90000	0	.000
4	90000	12	.048	90000	0	.000	90000	0	.000
5	90000	92	.368	90000	0	.000	90000	0	.000
6	90000	46	.184	90000	0	.000	90000	0	.000
7	90000	9	.036	90000	0	.000	90000	0	.000

SIMPLIFIED ELECTRICAL GENERATION SYSTEM (2 GTG'S)

CRITICAL EQUIPMENT BY EQUIPMENT NUMBER FOR FULL SYSTEM

UNAVAILABILITY AND
PERCENT OF UNAVAILABILITY

NAME	EQUIP NUMBER	EQUIP HRS	UNAVA	PERCENT	TYPE	NO.	FGC/EIC
GAS GENERATOR		8335.8950	.0463	49.84	1	1	
GAS GENERATOR		4535.5960	.0252	27.12	1	2	
POWER TURBINE		1531.1360	.0085	9.16	2	5	
SHIP REP COMP		698.2512	.0039	4.18	3	8	
SHIP REP COMP		681.1215	.0038	4.07	3	7	
SW CIRC PUMP		371.7098	.0021	2.22	5	14	
SW CIRC PUMP		325.5814	.0018	1.95	5	13	
POWER TURBINE		107.4628	.0006	.64	2	4	
CONTROL PANEL		43.6049	.0002	.26	6	16	
CONTROL PANEL		38.0814	.0002	.23	6	17	
SS GENERATOR		25.6171	.0001	.15	4	10	
SS GENERATOR		18.0653	.0001	.11	4	11	
DAU		10.0495	.0001	.06	7	19	
DAU		1.8083	.0000	.01	7	20	

SIMPLIFIED ELECTRICAL GENERATION SYSTEM (2 GTG'S)

CRITICAL EQUIPMENT BY EQUIPMENT TYPE FOR FULL SYSTEM

UNAVAILABILITY AND
PERCENT OF UNAVAILABILITY

NAME	EQUIP NUMBER HRS	UNAVA	PERCENT	TYPE	FGC/EIC
GAS GENERATOR	12871.4900	.0715	76.96	1	
POWER TURBINE	1638.5980	.0091	9.80	2	
SHIP REP COMP	1379.3730	.0077	8.25	3	
SW CIRC PUMP	697.2911	.0039	4.17	5	
CONTROL PANEL	81.6863	.0005	.49	6	
SS GENERATOR	43.6824	.0002	.26	4	
DAU	11.8578	.0001	.07	7	

TABLE RESPONSIBILITY TYPE   PAGE

SIMPLIFIED ELECTRICAL GENERATION SYSTEM (2 GTG'S)

PROPORTION OF EQUIPMENT DOWNTIME RESPONSIBLE FOR FULL SYSTEM DOWNTIME

CRITICAL EQUIPMENT BY EQUIPMENT TYPE

NAME	TYPE	PERCENT UNAVA	EQUIP TYPE DOWNTIME	PERCENT RESPONS.	FGC/EIC
DAU	7	.07	12.	100.00	
SS GENERATOR	4	.26	44.	100.00	
CONTROL PANEL	6	.49	82.	99.36	
SW CIRC PUMP	5	4.17	717.	97.26	
SHIP REP COMP	3	8.25	1420.	97.11	
POWER TURBINE	2	9.80	0.	.00	
GAS GENERATOR	1	76.96	0.	.00	

SIMPLIFIED ELECTRICAL GENERATION SYSTEM (2 GTG'S)

CRITICAL EQUIPMENT BY EQUIPMENT NUMBER FOR FULL SYSTEM

UNRELIABILITY AND
PERCENT OF MISSION FAILURES

DESCRIPTION	NO. FAILURES	UNREL	PERCENT	EQUIP TYPE	EQUIP NO.	FGC/EIC
SHIP REP COMP	37.0	.1480	19.37	3	8	
SW CIRC PUMP	34.0	.1360	17.80	5	14	
SHIP REP COMP	30.0	.1200	15.71	3	7	
SW CIRC PUMP	26.0	.1040	13.61	5	13	
GAS GENERATOR	14.0	.0560	7.33	1	1	
CONTROL PANEL	14.0	.0560	7.33	6	16	
GAS GENERATOR	10.0	.0400	5.24	1	2	
CONTROL PANEL	10.0	.0400	5.24	6	17	
SS GENERATOR	4.0	.0160	2.09	4	11	
DAU	4.0	.0160	2.09	7	19	
DAU	4.0	.0160	2.09	7	20	
SS GENERATOR	3.0	.0120	1.57	4	10	
POWER TURBINE	1.0	.0040	.52	2	5	

TOTAL NO. MISSION TRIALS = 250
TOTAL NO. MISSION FAILURES FOR FULL SYSTEM = 191

SIMPLIFIED ELECTRICAL GENERATION SYSTEM (2 GTG'S)

CRITICAL EQUIPMENT BY EQUIPMENT TYPE FOR FULL SYSTEM

UNRELIABILITY AND
PERCENT OF MISSION FAILURES

DESCRIPTION	NO. FAILURES	UNREL	PERCENT	EQUIP TYPE	FGC/EIC
SHIP REP COMP	67.0	.2680	35.08	3	
SW CIRC PUMP	60.0	.2400	31.41	5	
GAS GENERATOR	24.0	.0960	12.57	1	
CONTROL PANEL	24.0	.0960	12.57	6	
DAU	8.0	.0320	4.19	7	
SS GENERATOR	7.0	.0280	3.66	4	
POWER TURBINE	1.0	.0040	.52	2	

TOTAL NO. MISSION TRIALS = 250
TOTAL NO. MISSION FAILURES FOR FULL SYSTEM = 191

RESTRICTED ERLANG DISTRIBUTION MODEL

MTBMF =   520.56
2ND MOMENT ABOUT ORIGIN =   351617.80

SHAPE = 4   M1 =   31.84   M2 =   162.91

T	R-TIGER	R-THEO	DIFF	DIFSQ
720.00	.236	.208	.028	.001

AVG ABS DIFF= .028   MAX ABS DIFF= .028   SQUARESSUM= .001

TABLE SYS DIST   PAGE

DOWNTIME FREQUENCY DISTRIBUTION FOR FULL SYSTEM

DT INTERVAL	FREQ	CELL PROB	CUM PROB
.50	21	.0808	.0808
1.00	25	.0962	.1769
2.00	29	.1115	.2885
4.00	46	.1769	.4654
8.00	59	.2269	.6923
16.00	38	.1462	.8385
32.00	34	.1308	.9692
64.00	6	.0231	.9923
128.00	2	.0077	1.0000

THERE WAS NO DOWNTIME RECORDED FOR (SUB)SYSTEM GT GEN

Case 2: 2 of 3 Identical Gas Turbine Generators Required On Line

```
*********************************************************************
*********************************************************************
**** TIGER SIMULATION FOR RELIABILITY, MAINTAINABILITY, AND AVAILABILITY ****
*********************************************************************
*********************************************************************
```
SIMPLIFIED DDG-51 ELECTRICAL GENERATION SYSTEM

```
        ++++++++++++++++++++ TIGER 8.21 ++++++++++++++++++++
        +++++ NAVSEA 05MR  WASHINGTON, DC 20362-5101 +++++
        +++++++++++++++++++ (202) 692-2150 +++++++++++++++++++
```

INTIGER

RANDOM SEED IS   .0106203800
  250   0 .00 1.28   1357   1
1TIMELINE   PAGE

| TIMELINE | PHASE | DURATION | CUMULATIVE | CUMULATIVE |
SEQUENCE	TYPE	HOURS	HOURS	DAYS
1	1	720.00	720.00	30.00

TIMELINE SUMMARY BY PHASE

PHASE TYPE	HOURS	DAYS	PERCENT
1	720.00	30.00	100.00
TOTAL	720.00	30.00	100.00%

REPORT SELECTIONS

OPTION		1 2	3 4 5 6 7 8 9 10 11 12 13 14 15 16
4		1 0	0 0 0 0 0 0 0 0 0 0 1 1 1 1

SIMULATION DIMENSIONAL LIMITS (STANDARD TIGER OR TIGER READER)

MAXCTL	MAXEGR	MAXEXP	MAXGRP	MAXID	MAXLOC	MAXLNK	MAXLNX	MAXMBR
1000	20	50	1000	19	3	3000	1000	5000

MAXNEQ	MAXPH	MAXQUE	MAXRUL	MAXRUN	MAXSEQ	MAXSHP	MAXSTK	MAXSUB
500	6	50	1000	9999	100	21	100	31

MAXTYP	LUIN	LUOUT
200	5	6

PHASE REPAIR

       PHASE: 1
                       0
REPAIR ALLOWED: YES
EQPT TURNED ON: YES

| MULTIPLIERS | | SHOP | INVENTORY | MGMT | SPECIAL |
MTBF	MTTR	CAPACITY	DELAY	TRIGGER	SHOPS
1.00	1.00	500	.00	.00	0

INTYPES   PAGE

TYPE NOMENCLATURE	MTBF	MTTR	DC	ADT1	ADT2	ADT3	SHOP PRI	SWB
1 GAS GENERATOR	9300.0	9999.00	1.000	.0	.0	.0	GENL	0
2 POWER TURBINE	50000.0	9999.00	1.000	.0	.0	.0	GENL	0
3 SHIP REP COMP	3000.0	13.00	1.000	.0	.0	.0	GENL	0
4 SS GENERATOR	25000.0	6.00	1.000	.0	.0	.0	GENL	0
5 SW CIRC PUMP	3000.0	8.00	1.000	.0	.0	.0	GENL	0
6 CONTROL PANEL	5000.0	1.90	1.000	.0	.0	.0	GENL	0
7 DAU	25000.0	1.00	1.000	.0	.0	.0	GENL	0

INEQUIP   PAGE

TYPE EQUIPMENT ASSIGNED
```
1   1    2    3
2   4    5    6
3   7    8    9
4   10   11   12
5   13   14   15
6   16   17   18
7   19   20   21
```
INSPARES   PAGE

SPARES TYPE   ORG   INTER   DEPOT   FACTOR
ALL EQUIPMENT TYPES HAVE UNLIMITED SPARES
INCONFIG   PAGE

MISSION WILL BE RUN WITH 1 PHASE TYPES IN VARIABLE SEQUENCE.

```
ELEC   1    1  505
GT GEN         503    .00
  7 506   1   4   7  10  13  16  19
  7 507   2   5   8  11  14  17  20
  7 508   3   6   9  12  15  18  21
  2 505 506 507 508
STRING RULE    1 506
STRING RULE    4 506
STRING RULE    7 506
STRING RULE   10 506
STRING RULE   13 506
STRING RULE   16 506
STRING RULE   19 506
STRING RULE    2 507
STRING RULE    5 507
STRING RULE    8 507
STRING RULE   11 507
STRING RULE   14 507
STRING RULE   17 507
STRING RULE   20 507
STRING RULE    3 508
STRING RULE    6 508
STRING RULE    9 508
STRING RULE   12 508
STRING RULE   15 508
STRING RULE   18 508
```

STRING RULE 21 508
STNDBY RULE 506 508
STNDBY RULE 507 508

INPUT DATA HIGH VALUES

DURATION	TYPES	GROUPS	EQUIPS	PH-SEQ	PH-TYP	TRIALS
720.00	7	508	21	1	1	250

OUTTIGER   PAGE

RELIABILITY FOR PHASE 1, 1 .864   RELIABILITY THRU PHASE 1   .864
AVERAGE AVAILABILITY   AVG. AVAIL. THRU PHASE 1   .987
        FOR PHASE 1, 1 .987   TIME (END OF PHASE)   720.000
INSTANT AVAILABILITY   INSTANT AVAILABILITY
        AT BEGINNING OF PHASE 1.000   AT END OF PHASE .968
FINAL SUMMARY STATS   PAGE

SYSTEM FIGURES OF MERIT AFTER

250 MISSION TRIALS	MEAN	STANDARD DEVIATION OF THE SAMPLE MEAN
AT END OF MISSION:		
RELIABILITY	.864	.022
RELIABILITY LOWER PRECISION LIMIT		
(BASED ON STANDARD DEVIATION CRITERIA)	.836	
INSTANTANEOUS AVAILABILITY	.968	.011
AVERAGE AVAILABILITY	.987	.005
ESTIMATES OF LONG-TERM VALUES:		
MEAN TIME BETWEEN FAILURES	3513.0	
MEAN TIME TO REPAIR	50.6	
AVAILABILITY	.986	
MISSION PERFORMANCE (FAILURE & REPAIR INFORMATION		
CALCULATED FROM TIGER SIMULATION DATA):		
MEAN UP TIME	3779.2	3.890
MEAN DOWN TIME	50.6	3.890
MEAN REPAIR TIME	7.1	1.388
MEAN ACTIVE REPAIR TIME	7.1	1.388
MEAN TIME TO FIRST FAILURE	5013.4	743.141

TOTAL NO. OF SYSTEM FAILURES =   47

SUBSYSTEM	PHASE SEQ	TYPE	RELIABILITY TIME	IN PHASE	THRU	AVERAGE AVAILABILITY IN PHASE	THRU	INSTANT AVAILABILITY BEGIN	END
GT GEN	1	1	720.0	1.000	1.000	1.000	1.000	1.000	1.000

TABLE FAILURES NUM   PAGE

EQUIP FAILURE SUMMARY BY EQUIPMENT NUMBER

EQUIP. NO.	TYPE NO.	TOTAL EQUIP. FAILURES	AVG. NO. FAILURES PER MISSION	FGC/EIC
1	1	20	.080	
2	1	18	.072	
3	1	17	.068	
4	2	3	.012	
6	2	5	.020	
7	3	70	.280	
8	3	50	.200	
9	3	60	.240	
10	4	4	.016	
11	4	5	.020	
12	4	7	.028	
13	5	50	.200	
14	5	52	.208	
15	5	38	.152	
16	6	26	.104	
17	6	33	.132	
18	6	32	.128	
19	7	5	.020	
20	7	2	.008	
21	7	7	.028	
		504	2.016	

TABLE FAILURES TYPE   PAGE

EQUIP FAILURE SUMMARY BY EQUIPMENT TYPE NUMBER

TYPE	TOTAL EQUIP. FAILURES	AVG. NO. FAILURES PER MISSION	MAINTENANCE HOURS	STD. DEV. MAINT. HRS	FGC/EIC
1	55	.220	.000	.000	
2	8	.032	.000	.000	
3	180	.720	1950.704	1.099	
4	16	.064	100.236	1.446	
5	140	.560	1402.631	1.243	
6	91	.364	193.537	.260	
7	14	.056	10.736	.239	
	504	2.016	30.014		

117

UNLIMITED SPARES
SUMMARY OF SPARES USED

	ORGANIZATION SPARES			INTERMEDIATE SPARES			DEPOT SPARES		
SPARE TYPE	STOCK	TOTAL USED	USE PER MISSION	STOCK	TOTAL USED	USE PER MISSION	STOCK	TOTAL USED	USE PER MISSION
1	90000	0	.000	90000	0	.000	90000	0	.000
2	90000	0	.000	90000	0	.000	90000	0	.000
3	90000	180	.720	90000	0	.000	90000	0	.000
4	90000	16	.064	90000	0	.000	90000	0	.000
5	90000	140	.560	90000	0	.000	90000	0	.000
6	90000	91	.364	90000	0	.000	90000	0	.000
7	90000	14	.056	90000	0	.000	90000	0	.000

TABLE UNAVA NUM   PAGE

SIMPLIFIED DDG-51 ELECTRICAL GENERATION SYSTEM

CRITICAL EQUIPMENT BY EQUIPMENT NUMBER FOR FULL SYSTEM

UNAVAILABILITY AND
PERCENT OF UNAVAILABILITY

NAME	NUMBER HRS	EQUIP UNAVA	PERCENT	EQUIP TYPE	NO.	FGC/EIC
GAS GENERATOR	881.3107	.0049	37.07	1	2	
GAS GENERATOR	573.3938	.0032	24.12	1	3	
GAS GENERATOR	438.8444	.0024	18.46	1	1	
POWER TURBINE	310.6342	.0017	13.07	2	6	
SW CIRC PUMP	69.1658	.0004	2.91	5	14	
SHIP REP COMP	19.2311	.0001	.81	3	9	
SHIP REP COMP	19.0246	.0001	.80	3	7	
SW CIRC PUMP	18.9908	.0001	.80	5	15	
SHIP REP COMP	14.2743	.0001	.60	3	8	
SW CIRC PUMP	14.1480	.0001	.60	5	13	
POWER TURBINE	10.8248	.0001	.46	2	4	
CONTROL PANEL	2.7453	.0000	.12	6	17	
SS GENERATOR	1.7836	.0000	.08	4	11	
SS GENERATOR	1.4147	.0000	.06	4	12	
CONTROL PANEL	.9914	.0000	.04	6	18	
DAU	.5433	.0000	.02	7	19	
DAU	.1189	.0000	.01	7	21	
CONTROL PANEL	.0317	.0000	.00	6	16	

TABLE UNAVA TYPE   PAGE

SIMPLIFIED DDG-51 ELECTRICAL GENERATION SYSTEM

CRITICAL EQUIPMENT BY EQUIPMENT TYPE FOR FULL SYSTEM

UNAVAILABILITY AND
PERCENT OF UNAVAILABILITY

NAME	NUMBER HRS	UNAVA	PERCENT	EQUIP TYPE	FGC/EIC
GAS GENERATOR	1893.5490	.0105	79.65	1	
POWER TURBINE	321.4591	.0018	13.52	2	
SW CIRC PUMP	102.3046	.0006	4.30	5	
SHIP REP COMP	52.5300	.0003	2.21	3	
CONTROL PANEL	3.7684	.0000	.16	6	
SS GENERATOR	3.1983	.0000	.13	4	
DAU	.6622	.0000	.03	7	

TABLE RESPONSIBILITY TYPE   PAGE

SIMPLIFIED DDG-51 ELECTRICAL GENERATION SYSTEM

PROPORTION OF EQUIPMENT DOWNTIME RESPONSIBLE FOR FULL SYSTEM DOWNTIME

CRITICAL EQUIPMENT BY EQUIPMENT TYPE

NAME	TYPE	PERCENT UNAVA	EQUIP TYPE DOWNTIME	PERCENT RESPONS.	FGC/EIC
SW CIRC PUMP	5	4.30	1403.	7.29	
DAU	7	.03	11.	6.17	
SS GENERATOR	4	.13	100.	3.19	
SHIP REP COMP	3	2.21	1951.	2.69	
CONTROL PANEL	6	.16	194.	1.95	
GAS GENERATOR	1	79.65	0.	.00	
POWER TURBINE	2	13.52	0.	.00	

SIMPLIFIED DDG-51 ELECTRICAL GENERATION SYSTEM

CRITICAL EQUIPMENT BY EQUIPMENT NUMBER FOR FULL SYSTEM

UNRELIABILITY AND
PERCENT OF MISSION FAILURES

DESCRIPTION	NO. FAILURES	UNREL	PERCENT	EQUIP TYPE	EQUIP NO.	GC/EIC
GAS GENERATOR	5.5	.0220	16.18	1	2	
GAS GENERATOR	4.5	.0180	13.24	1	1	
GAS GENERATOR	4.5	.0180	13.24	1	3	
SHIP REP COMP	3.5	.0140	10.29	3	9	
SHIP REP COMP	3.0	.0120	8.82	3	8	
SW CIRC PUMP	3.0	.0120	8.82	5	14	
POWER TURBINE	2.5	.0100	7.35	2	6	
SHIP REP COMP	2.0	.0080	5.88	3	7	
CONTROL PANEL	1.5	.0060	4.41	6	17	
SW CIRC PUMP	1.0	.0040	2.94	5	15	
CONTROL PANEL	1.0	.0040	2.94	6	18	
SW CIRC PUMP	.5	.0020	1.47	5	13	
CONTROL PANEL	.5	.0020	1.47	6	16	
SS GENERATOR	.5	.0020	1.47	4	12	
POWER TURBINE	.5	.0020	1.47	2	4	

TOTAL NO. MISSION TRIALS = 250
TOTAL NO. MISSION FAILURES FOR FULL SYSTEM = 34

SIMPLIFIED DDG-51 ELECTRICAL GENERATION SYSTEM

CRITICAL EQUIPMENT BY EQUIPMENT TYPE FOR FULL SYSTEM

UNRELIABILITY AND
PERCENT OF MISSION FAILURES

DESCRIPTION	NO. FAILURES	UNREL	PERCENT	EQUIP TYPE	FGC/EIC
GAS GENERATOR	14.5	.0580	42.65	1	
SHIP REP COMP	8.5	.0340	25.00	3	
SW CIRC PUMP	4.5	.0180	13.24	5	
POWER TURBINE	3.0	.0120	8.82	2	
CONTROL PANEL	3.0	.0120	8.82	6	
SS GENERATOR	.5	.0020	1.47	4	

TOTAL NO. MISSION TRIALS = 250
TOTAL NO. MISSION FAILURES FOR FULL SYSTEM = 34

RESTRICTED ERLANG DISTRIBUTION MODEL

MTBMF =   5013.36
2ND MOMENT ABOUT ORIGIN =   43910580.00

SHAPE = 2 M1 =   744.60 M2 =   4268.76

T	R-TIGER	R-THEO	DIFF	DIFSQ
720.00	.864	.943	-.079	.006

AVG ABS DIFF= .079   MAX ABS DIFF= .079   SQUARESSUM= .006

TABLE SYS DIST   PAGE

DOWNTIME FREQUENCY DISTRIBUTION FOR FULL SYSTEM

DT INTERVAL	FREQ	CELL PROB	CUM PROB
.50	4	.1026	.1026
1.00	5	.1282	.2308
2.00	6	.1538	.3846
4.00	5	.1282	.5128
8.00	7	.1795	.6923
16.00	5	.1282	.8205
32.00	6	.1538	.9744
64.00	1	.0256	1.0000

THERE WAS NO DOWNTIME RECORDED FOR (SUB)SYSTEM GT GEN

Case 3: 2 of 4 Identical Gas Turbine Generators Required On Line

```
*************************************************************************
*************************************************************************
**** TIGER SIMULATION FOR RELIABILITY, MAINTAINABILITY, AND AVAILABILITY ****
*************************************************************************
*************************************************************************
```

SIMPLIFIED ELECTRICAL GENERATION SYSTEM (4 GTG'S)

```
+++++++++++++++++++ TIGER 8.21 +++++++++++++++++++
+++++ NAVSEA 05MR  WASHINGTON, DC 20362-5101 +++++
+++++++++++++++++++ (202) 692-2150 +++++++++++++++++++
```

INTIGER

RANDOM SEED IS   .0106203800
 250   0 .00 1.28 1357   1
TIMELINE   PAGE

TIMELINE SEQUENCE	PHASE TYPE	DURATION HOURS	CUMULATIVE HOURS	CUMULATIVE DAYS
1	1	720.00	720.00	30.00

TIMELINE SUMMARY BY PHASE

PHASE TYPE	HOURS	DAYS	PERCENT
1	720.00	30.00	100.00
TOTAL	720.00	30.00	100.00%

REPORT SELECTIONS

OPTION	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
4	1 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1

SIMULATION DIMENSIONAL LIMITS (STANDARD TIGER OR TIGER READER)

MAXCTL	MAXEGR	MAXEXP	MAXGRP	MAXID	MAXLOC	MAXLNK	MAXLNX	MAXMBR
1000	20	50	1000	19	3	3000	1000	5000

MAXNEQ	MAXPH	MAXQUE	MAXRUL	MAXRUN	MAXSEQ	MAXSHP	MAXSTK	MAXSUB
500	6	50	1000	9999	100	21	100	31

MAXTYP	LUIN	LUOUT
200	5	6

PHASE REPAIR

PHASE: 1
     0
REPAIR ALLOWED: YES
EQPT TURNED ON: YES

MULTIPLIERS		SHOP	INVENTORY MGMT		SPECIAL
MTBF	MTTR	CAPACITY	DELAY	TRIGGER	SHOPS
1.00	1.00	500	.00	.00	0

TYPE NOMENCLATURE	MTBF	MTTR	DC	ADT1	ADT2	ADT3	SHOP PRI SWB
1 GAS GENERATOR	9300.0	9999.00	1.000	.0	.0	.0	GENL 0
2 POWER TURBINE	50000.0	9999.00	1.000	.0	.0	.0	GENL 0
3 SHIP REP COMP	3000.0	13.00	1.000	.0	.0	.0	GENL 0
4 SS GENERATOR	25000.0	6.00	1.000	.0	.0	.0	GENL 0
5 SW CIRC PUMP	3000.0	8.00	1.000	.0	.0	.0	GENL 0
6 CONTROL PANEL	5000.0	1.90	1.000	.0	.0	.0	GENL 0
7 DAU	25000.0	1.00	1.000	.0	.0	.0	GENL 0

INEQUIP   PAGE

TYPE EQUIPMENT ASSIGNED
```
1   1   2   3   22
2   4   5   6   23
3   7   8   9   24
4  10  11  12   25
5  13  14  15   26
6  16  17  18   27
7  19  20  21   28
```
INSPARES   PAGE

SPARES TYPE   ORG   INTER   DEPOT   FACTOR
ALL EQUIPMENT TYPES HAVE UNLIMITED SPARES
INCONFIG   PAGE

MISSION WILL BE RUN WITH 1 PHASE TYPES IN VARIABLE SEQUENCE.

```
ELEC   1   1  505
GT GEN        503   .00
  7 506   1   4   7  10  13  16  19
  7 507   2   5   8  11  14  17  20
  7 508   3   6   9  12  15  18  21
  7 509  22  23  24  25  26  27  28
  2 505 506 507 508 509
```
STRING RULE   1 506
STRING RULE   4 506
STRING RULE   7 506
STRING RULE 10 506
STRING RULE 13 506
STRING RULE 16 506
STRING RULE 19 506
STRING RULE   2 507
STRING RULE   5 507
STRING RULE   8 507
STRING RULE 11 507
STRING RULE 14 507
STRING RULE 17 507
STRING RULE 20 507
STRING RULE   3 508
STRING RULE   6 508
STRING RULE   9 508
STRING RULE 12 508
STRING RULE 15 508

```
STRING RULE  18 508
STRING RULE  21 508
STRING RULE  22 509
STRING RULE  23 509
STRING RULE  24 509
STRING RULE  25 509
STRING RULE  26 509
STRING RULE  27 509
STRING RULE  28 509
STNDBY RULE  506 508
STNDBY RULE  507 509
```

INPUT DATA HIGH VALUES

DURATION	TYPES	GROUPS	EQUIPS	PH-SEQ	PH-TYP	TRIALS
720.00	7	509	28	1	1	250

OUTTIGER   PAGE

RELIABILITY FOR PHASE 1, 1 .980   RELIABILITY THRU PHASE 1   .980
AVERAGE AVAILABILITY   AVG. AVAIL. THRU PHASE 1   .999
        FOR PHASE 1, 1 .999   TIME (END OF PHASE)   720.000
INSTANT AVAILABILITY   INSTANT AVAILABILITY
        AT BEGINNING OF PHASE 1.000   AT END OF PHASE .996
FINAL SUMMARY STATS   PAGE

SYSTEM FIGURES OF MERIT AFTER

250 MISSION TRIALS	MEAN	STANDARD DEVIATION OF THE SAMPLE MEAN
AT END OF MISSION:		
RELIABILITY	.980	.009
RELIABILITY LOWER PRECISION LIMIT (BASED ON STANDARD DEVIATION CRITERIA)	.969	
INSTANTANEOUS AVAILABILITY	.996	.004
AVERAGE AVAILABILITY	.999	.001

ESTIMATES OF LONG-TERM VALUES:

MEAN TIME BETWEEN FAILURES	29218.3	
MEAN TIME TO REPAIR	18.2	
AVAILABILITY	.999	

MISSION PERFORMANCE (FAILURE & REPAIR INFORMATION
   CALCULATED FROM TIGER SIMULATION DATA):

MEAN UP TIME	29981.8	.376
MEAN DOWN TIME	18.2	.376
MEAN REPAIR TIME	3.2	1.954
MEAN ACTIVE REPAIR TIME	3.2	1.954
MEAN TIME TO FIRST FAILURE	35881.0	15725.560

   TOTAL NO. OF SYSTEM FAILURES =   6

SUBSYSTEM	PHASE SEQ	TYPE	TIME	AVERAGE RELIABILITY IN PHASE	THRU	INSTANT AVAILABILITY IN PHASE	THRU	AVAILABILITY BEGIN	END
GT GEN	1	1	720.0	1.000	1.000	1.000	1.000	1.000	1.000

TABLE FAILURES NUM   PAGE

EQUIP FAILURE SUMMARY BY EQUIPMENT NUMBER

EQUIP. NO.	TYPE NO.	TOTAL EQUIP. FAILURES	AVG. NO. FAILURES PER MISSION	FGC/EIC
1	1	13	.052	
2	1	19	.076	
3	1	15	.060	
5	2	5	.020	
6	2	8	.032	
7	3	51	.204	
8	3	53	.212	
9	3	53	.212	
10	4	3	.012	
11	4	7	.028	
12	4	8	.032	
13	5	58	.232	
14	5	50	.200	
15	5	53	.212	
16	6	32	.128	
17	6	28	.112	
18	6	33	.132	
19	7	6	.024	
20	7	5	.020	
21	7	5	.020	
22	1	13	.052	
23	2	4	.016	
24	3	46	.184	
25	4	11	.044	
26	5	49	.196	
27	6	29	.116	
28	7	3	.012	
		660	2.640	

TABLE FAILURES TYPE   PAGE

EQUIP FAILURE SUMMARY BY EQUIPMENT TYPE NUMBER

TYPE	TOTAL EQUIP. FAILURES	AVG. NO. FAILURES PER MISSION	MAINTENANCE HOURS	STD. DEV. MAINT. HRS	FGC/EIC
1	60	.240	.000	.000	
2	17	.068	.000	.000	
3	203	.812	2433.645	1.159	
4	29	.116	165.411	1.446	
5	210	.840	1614.073	.658	
6	122	.488	206.779	.185	
7	19	.076	18.612	.196	
	660	2.640	28.053		

TABLE SPARES LEVEL   PAGE

UNLIMITED SPARES
SUMMARY OF SPARES USED

	ORGANIZATION SPARES			INTERMEDIATE SPARES			DEPOT SPARES		
SPARE TYPE	STOCK	TOTAL USED	USE PER MISSION	STOCK	TOTAL USED	USE PER MISSION	STOCK	TOTAL USED	USE PER MISSION
1	90000	0	.000	90000	0	.000	90000	0	.000
2	90000	0	.000	90000	0	.000	90000	0	.000
3	90000	203	.812	90000	0	.000	90000	0	.000
4	90000	29	.116	90000	0	.000	90000	0	.000
5	90000	210	.840	90000	0	.000	90000	0	.000
6	90000	122	.488	90000	0	.000	90000	0	.000
7	90000	19	.076	90000	0	.000	90000	0	.000

TABLE UNAVA NUM   PAGE

SIMPLIFIED ELECTRICAL GENERATION SYSTEM (4 GTG'S)

CRITICAL EQUIPMENT BY EQUIPMENT NUMBER FOR FULL SYSTEM

UNAVAILABILITY AND
PERCENT OF UNAVAILABILITY

NAME	NUMBER HRS	UNAVA	PERCENT	EQUIP TYPE	EQUIP NO.	FGC/EIC
POWER TURBINE	35.0497	.0002	32.03	2	6	
GAS GENERATOR	32.0418	.0002	29.28	1	1	
POWER TURBINE	30.8997	.0002	28.24	2	5	
SHIP REP COMP	4.6163	.0000	4.22	3	24	
GAS GENERATOR	4.0150	.0000	3.67	1	2	
GAS GENERATOR	1.3989	.0000	1.28	1	22	
SW CIRC PUMP	.6333	.0000	.58	5	14	
CONTROL PANEL	.5697	.0000	.52	6	18	
CONTROL PANEL	.1959	.0000	.18	6	16	

TABLE UNAVA TYPE   PAGE

SIMPLIFIED ELECTRICAL GENERATION SYSTEM (4 GTG'S)

CRITICAL EQUIPMENT BY EQUIPMENT TYPE FOR FULL SYSTEM

UNAVAILABILITY AND
PERCENT OF UNAVAILABILITY

NAME	NUMBER HRS	UNAVA	PERCENT	EQUIP TYPE	FGC/EIC
POWER TURBINE	65.9494	.0004	60.27	2	
GAS GENERATOR	37.4557	.0002	34.23	1	
SHIP REP COMP	4.6163	.0000	4.22	3	
CONTROL PANEL	.7656	.0000	.70	6	
SW CIRC PUMP	.6333	.0000	.58	5	

TABLE RESPONSIBILITY TYPE   PAGE

SIMPLIFIED ELECTRICAL GENERATION SYSTEM (4 GTG'S)

PROPORTION OF EQUIPMENT DOWNTIME RESPONSIBLE FOR FULL SYSTEM DOWNTIME

CRITICAL EQUIPMENT BY EQUIPMENT TYPE

NAME	TYPE	PERCENT UNAVA	EQUIP TYPE DOWNTIME	PERCENT RESPONS.	FGC/EIC
CONTROL PANEL	6	.70	207.	.37	
SHIP REP COMP	3	4.22	2434.	.19	
SW CIRC PUMP	5	.58	1614.	.04	
POWER TURBINE	2	60.27	0.	.00	
GAS GENERATOR	1	34.23	0.	.00	

TABLE UNREL NUM   PAGE

SIMPLIFIED ELECTRICAL GENERATION SYSTEM (4 GTG'S)

CRITICAL EQUIPMENT BY EQUIPMENT NUMBER FOR FULL SYSTEM

UNRELIABILITY AND
PERCENT OF MISSION FAILURES

DESCRIPTION	NO. FAILURES	UNREL	PERCENT	EQUIP TYPE	EQUIP NO.	FGC/EIC
POWER TURBINE	1.0	.0040	20.00	2	6	
GAS GENERATOR	1.0	.0040	20.00	1	22	
GAS GENERATOR	.7	.0027	13.33	1	1	
GAS GENERATOR	.7	.0027	13.33	1	2	
SW CIRC PUMP	.3	.0013	6.67	5	14	
CONTROL PANEL	.3	.0013	6.67	6	16	
CONTROL PANEL	.3	.0013	6.67	6	18	
POWER TURBINE	.3	.0013	6.67	2	5	
SHIP REP COMP	.3	.0013	6.67	3	24	

TOTAL NO. MISSION TRIALS = 250
TOTAL NO. MISSION FAILURES FOR FULL SYSTEM = 5
TABLE UNREL TYPE   PAGE

SIMPLIFIED ELECTRICAL GENERATION SYSTEM (4 GTG'S)

CRITICAL EQUIPMENT BY EQUIPMENT TYPE FOR FULL SYSTEM

UNRELIABILITY AND
PERCENT OF MISSION FAILURES

DESCRIPTION	NO. FAILURES	UNREL	PERCENT	EQUIP TYPE	FGC/EIC
GAS GENERATOR	2.3	.0093	46.67	1	
POWER TURBINE	1.3	.0053	26.67	2	
CONTROL PANEL	.7	.0027	13.33	6	
SW CIRC PUMP	.3	.0013	6.67	5	
SHIP REP COMP	.3	.0013	6.67	3	

TOTAL NO. MISSION TRIALS = 250
TOTAL NO. MISSION FAILURES FOR FULL SYSTEM = 5
TABLE REDM   PAGE

RESTRICTED ERLANG DISTRIBUTION MODEL

MTBMF =   35881.03
2ND MOMENT ABOUT ORIGIN =   2523914000.00

SHAPE = 2   M1 =   725.09   M2 =   35155.94

T	R-TIGER	R-THEO	DIFF	DIFSQ
720.00	.980	.993	-.013	.000

AVG ABS DIFF= .013   MAX ABS DIFF= .013   SQUARESSUM= .000

DOWNTIME FREQUENCY DISTRIBUTION FOR FULL SYSTEM

DT INTERVAL	FREQ	CELL PROB	CUM PROB
.50	1	.2000	.2000
1.00	1	.2000	.4000
2.00	2	.4000	.8000
4.00	0	.0000	.8000
8.00	0	.0000	.8000
16.00	1	.2000	1.0000

THERE WAS NO DOWNTIME RECORDED FOR (SUB)SYSTEM GT GEN

Appendix C. ASSET Output Files

DDG-51 Output Files

ADVANCED SURFACE SHIP EVALUATION TOOL (ASSET)
MONOHULL SURFACE COMBATANT PROGRAM (MONOSC)
VERSION 3.3
DATED OCTOBER 23, 1992

ASSET/MONOSC VERSION 3.3 - RESISTANCE MODULE - 3/11/93 11.37.52.

PRINTED REPORT NO. 1 - SUMMARY

RESID RESIST IND	TAYLOR	BILGE KEEL IND	PRESENT
FRICTION LINE IND	ITTC	SHAFT SUPPORT TYPE IND	OPEN STRUT
ENDUR DISP IND	AVG DISP	PRPLN SYS RESIST IND	CALC
ENDUR CONFIG IND	NO TS	PROP TYPE IND	CP
SONAR DRAG IND	HULL	SONAR DOME IND	PRESENT
SKEG IND	PRESENT	RUDDER TYPE IND	SPADE

FULL LOAD WT, LTON	8314.0	CORR ALW	0.00040
AVG ENDUR DISP, LTON	8013.9	DRAG MARGIN FAC	0.080
USABLE FUEL WT, LTON	1127.6	TRAILSHAFT PWR FAC	
NO RUDDERS	2.		
NO FIN PAIRS	0.	PRPLN SYS RESIST FRAC	
PROP TIP CLEAR RATIO	0.16	MAX SPEED	0.146
NO PROP SHAFTS	2.	SUSTN SPEED	0.162
PROP DIA, FT	17.00	ENDUR SPEED	0.329

PRINTED REPORT NO. 2 - SPEED-POWER MATRIX

RESID RESIST IND	TAYLOR
ENDUR DISP IND	AVG DISP

SPEED AND POWER FOR FULL LOAD DISP

FULL LOAD WT, LTON   8314.0

SPEED	----------EFFECTIVE HORSEPOWER, HP----------						DRAG
KT	FRIC	RESID	APPDG	WIND	MARGIN	TOTAL	LBF
2.00	5.	2.	6.	0.	1.	15.	2387.
4.00	39.	14.	40.	2.	7.	101.	8205.
6.00	125.	46.	115.	5.	23.	314.	17029.
8.00	287.	108.	244.	13.	52.	704.	28683.
10.00	547.	211.	440.	25.	98.	1321.	43060.
12.00	928.	396.	715.	43.	167.	2249.	61062.
14.00	1451.	719.	1081.	68.	266.	3585.	83439.
16.00	2138.	1143.	1544.	101.	394.	5320.	108359.
18.00	3009.	1673.	2114.	144.	555.	7495.	135693.
20.00	4085.	2597.	2815.	198.	776.	10471.	170607.
22.00	5388.	4521.	3691.	264.	1109.	14973.	221778.
24.00	6937.	6615.	4699.	342.	1487.	20080.	272637.
26.00	8753.	9773.	5896.	435.	1989.	26846.	336467.
28.00	10856.	16671.	7442.	543.	2841.	38354.	446364.
30.00	13267.	27524.	9345.	668.	4064.	54868.	595992.
32.00	16005.	39700.	11460.	811.	5438.	73414.	747600.
34.00	19090.	51115.*	13681.	973.	6789.	91647.	878374.

SPEED AND POWER FOR AVE ENDUR DISP

AVE ENDUR DISP, LTON   8013.9

SPEED	----------EFFECTIVE HORSEPOWER, HP----------						DRAG
KT	FRIC	RESID	APPDG	WIND	MARGIN	TOTAL	LBF
2.00	5.	2.	6.	0.	1.	14.	2363.
4.00	38.	13.	39.	2.	7.	100.	8116.
6.00	123.	45.	114.	5.	23.	310.	16834.
8.00	282.	106.	244.	13.	52.	696.	28346.
10.00	538.	206.	439.	25.	97.	1306.	42544.
12.00	913.	387.	713.	43.	165.	2221.	60314.
14.00	1428.	700.	1078.	68.	262.	3536.	82300.
16.00	2103.	1116.	1540.	102.	389.	5251.	106938.
18.00	2960.	1622.	2107.	146.	547.	7382.	133643.
20.00	4019.	2425.	2800.	200.	756.	10200.	166199.
22.00	5301.	4158.	3664.	266.	1071.	14460.	214183.
24.00	6825.	6168.	4666.	345.	1440.	19444.	264002.
26.00	8612.	9226.	5856.	439.	1931.	26064.	326666.
28.00	10681.	15791.	7382.	548.	2752.	37154.	432398.
30.00	13053.	26352.	9268.	674.	3948.	53294.	578890.
32.00	15747.	38330.	11371.	818.	5301.	71566.	728782.
34.00	18782.	49271.*	13564.	981.	6608.	89206.	854978.

* DENOTES EXTRAPOLATED VALUE.

PRINTED REPORT NO. 1 - SUMMARY

ENDUR CONFIG IND	NO TS		
PROP TYPE IND	CP	PROP SERIES IND	GIVEN
PROP DIA IND	GIVEN	PROP LOC IND	GIVEN
PROP AREA IND	GIVEN	PROP ID IND	MODEL 4988
SHAFT SUPPORT TYPE IND		RUDDER TYPE IND	

MAX SPEED, KT	31.24	ENDUR SPEED, KT	20.00
MAX EHP (/SHAFT), HP	33361.	ENDUR EHP (/SHAFT), HP	5100.
MAX SHP (/SHAFT), HP	50272.	ENDUR SHP (/SHAFT), HP	7166.
MAX PROP RPM	160.4	ENDUR PROP RPM	90.4
MAX PROP EFF	0.699	ENDUR PROP EFF	0.749

SUSTN SPEED, KT	29.90	PROP DIA, FT	17.00
SUSTN EHP (/SHAFT), HP	26958.	NO BLADES	5.
SUSTN SHP (/SHAFT), HP	40125.	PITCH RATIO	1.72
SUSTN PROP RPM	150.3	EXPAND AREA RATIO	0.784
SUSTN PROP EFF	0.707	CAVITATION NO	1.21

NO PROP SHAFTS   2.0

TOTAL PROPELLER WT, LTON   51.62

PRINTED REPORT NO. 2 - PROPELLER CHARACTERISTICS

PROP ID IND	MODEL 4988
NO PROP SHAFTS	2.
PROP DIA, FT	17.00
NO BLADES	5.
PITCH RATIO	1.72
EXPAND AREA RATIO	0.784
THRUST DED COEF	0.055
TAYLOR WAKE FRAC	0.020
HULL EFFICIENCY	0.964
REL ROTATE EFF	0.985

	——— CONDITIONS ———		
CHARACTERISTICS	MAXIMUM	SUSTAINED	ENDURANCE
SPEED, KT	31.24	29.90	20.00
RPM	160.4	150.3	90.4
THRUST/SHAFT, LBF	368287.	310944.	87937.
EHP/SHAFT, HP	33361.	26958.	5100.
TORQUE/SHAFT, FT-LBF	1622096.	1381287.	409923.
SHP/SHAFT, HP	50272.	40125.	7166.
ADVANCE COEF (J)	1.137	1.161	1.291
THRUST COEF (KT)	0.310	0.298	0.233
TORQUE COEF (10KQ)	0.803	0.779	0.638
OPEN WATER EFFY	0.699	0.707	0.749
PC	0.664	0.672	0.712

132

ASSET/MONOSC VERSION 3.3 - MACHINERY MODULE - 3/11/93 11.38.36.

PRINTED REPORT NO. 1 - SUMMARY

TRANS TYPE IND	MECH	MAX SPEED, KT	31.24
ELECT PRPLN TYPE IND		SUSTN SPEED IND	CALC
SHAFT SUPPORT TYPE IND	OPEN STRUT	SUSTN SPEED, KT	29.90
NO PROP SHAFTS	2.	ENDUR SPEED IND	GIVEN
ENDUR CONFIG IND	NO TS	ENDUR SPEED, KT	20.00
SEC ENG USAGE IND		DESIGN MODE IND	FUEL WT
MAX MARG ELECT LOAD, KW	3644.	ENDURANCE, NM	3873.
AVG 24 HR ELECT LOAD, KW	2365.	USABLE FUEL WT, LTON	1127.6
SWBS 200 GROUP WT, LTON	813.9	SUSTN SPEED POWER FRAC	0.80
SWBS 300 GROUP WT, LTON	394.1		

PRINTED REPORT NO. 6 - SHIP SERVICE GENERATORS

SS SYS TYPE IND-SEP
GEN SIZE IND-GIVEN

ELECT LOAD DES MARGIN FAC 0.000
ELECT LOAD SL MARGIN FAC   0.010
ELECT LOAD IMBAL FAC   0.900
MAX MARG ELECT LOAD, KW   3644.1
MAX STANDBY LOAD, KW   2786.1
24 HR AVG ELECT LOAD, KW 2365.2

VSCF SS CYCLOCONVERTERS

CONDITION	NO INSTALL	NO ONLINE	REQ KW/CYCLO	AVAIL KW/CYCLO	LOADING FRAC
WINTER BATTLE	0	0			0.000
WINTER CRUISE	0	0			0.000
SUMMER CRUISE	0	0			0.000
ENDURANCE(24 HR AVG)0		0			0.000

SEPARATE SS GENERATORS

CONDITION	NO INSTALL	NO ONLINE	REQ KW/GEN	AVAIL KW/GEN	LOADING FRAC
WINTER BATTLE	3	2	1822.	2500.	0.729
WINTER CRUISE	3	2	1778.	2500.	0.711
SUMMER CRUISE	3	2	1499.	2500.	0.600
ENDURANCE(24 HR AVG)	3	2	1183.	2500.	0.473

TOTALS

CONDITION	REQ KW	AVAIL KW	LOADING FRAC
WINTER BATTLE	3644.	5000.	0.729
WINTER CRUISE	3556.	5000.	0.711
SUMMER CRUISE	2999.	5000.	0.600
ENDURANCE(24 HR AVG)	2365.	5000.	0.473

PRINTED REPORT NO. 11 - ELECTRIC LOADS

400 HZ ELECT LOAD FAC   0.200

PAYLOAD LOADS	WINTER CRUISE KW	WINTER BATTLE KW	SUMMER CRUISE KW
COMMAND AND SURVEILLANCE (60 HZ)	559.1	778.0	559.1
COMMAND AND SURVEILLANCE (400 HZ)	139.8	194.5	139.8
ARMAMENT (60 HZ)	119.1	162.1	119.1
ARMAMENT (400 HZ)	29.8	40.5	29.8
OTHER PAYLOAD (60 HZ)	0.0	0.0	0.0
OTHER PAYLOAD (400 HZ)	0.0	0.0	0.0
SUB-TOTAL	847.8	1175.1	847.8

NON-PAYLOAD LOADS (* INDICATES USER ADJUSTED VALUE)

	WINTER CRUISE KW	WINTER BATTLE KW	SUMMER CRUISE KW
PROPULSION AND STEERING	801.9*	1037.9*	538.0*
LIGHTING	170.5*	166.7*	170.5*
MISCELLANEOUS ELECTRIC	47.0*	64.8*	45.6*
HEATING	556.2*	326.7*	55.4*
VENTILATION	389.1*	302.5*	389.1*
AIR CONDITIONING	318.9*	368.5*	530.5*
AUXILIARY BOILER AND FRESH WATER	205.2*	23.9*	205.2*
FIREMAIN	57.8*	92.2*	57.8*
UNREP AND HANDLING	4.5*	0.2*	4.5*
MISC AUXILIARY MACHINERY	26.3*	29.3*	26.3*
SERVICES AND WORK SPACES	103.7*	30.6*	103.7*
SUBTOTAL	2681.1	2443.2	2126.5
TOTAL	3528.9	3618.3	2974.3
TOTAL (INCLUDING MARGINS)	3556.1	3644.1	2998.7

MAX MARG ELECT LOAD	3644.1
24 HR AVG ELECT LOAD	2365.2
CONNECTED ELECT LOAD	9588.6
ANCHOR ELECT LOAD	2786.1
VITAL ELECT LOAD	1884.1
EMERGENCY ELECT LOAD	1076.0
MAX STBY ELECT LOAD	2786.1

AL   NCED SURFACE SHIP EVALUATION TOOL (ASSET)
MONOHULL L AND A TYPE SHIPS (MONOLA)
VERSION 1.0
DATED OCTOBER 28, 1992

ASSET/MONOLA VERSION 1.0 - RESISTANCE MODULE - 3/18/93 14.45.26.

PRINTED REPORT NO. 1 - SUMMARY

RESID RESIST IND	TAYLOR	BILGE KEEL IND	PRESENT
FRICTION LINE IND	ITTC	SHAFT SUPPORT TYPE IND	POD
ENDUR DISP IND	FULL LOAD	PRPLN SYS RESIST IND	CALC
ENDUR CONFIG IND	NO TS	PROP TYPE IND	FP
SONAR DRAG IND		SONAR DOME IND	NONE
SKEG IND	NONE	RUDDER TYPE IND	INTEGRAL

FULL LOAD WT, LTON	41170.6	CORR ALW	0.00050
AVG ENDUR DISP, LTON	41170.6	DRAG MARGIN FAC	0.110
USABLE FUEL WT, LTON	4837.4	TRAILSHAFT PWR FAC	
NO RUDDERS	2.		
NO FIN PAIRS	0.	PRPLN SYS RESIST FRAC	
PROP TIP CLEAR RATIO	0.10	MAX SPEED	0.120
NO PROP SHAFTS	2.	SUSTN SPEED	0.127
PROP DIA, FT	14.14	ENDUR SPEED	0.127

PRINTED REPORT NO. 2 - SPEED-POWER MATRIX

RESID RESIST IND	TAYLOR
ENDUR DISP IND	FULL LOAD

SPEED AND POWER FOR FULL LOAD DISP

FULL LOAD WT, LTON   41170.6

SPEED	EFFECTIVE HORSEPOWER, HP						DRAG
KT	FRIC	RESID	APPDG	WIND	MARGIN	TOTAL	LBF
2.00	17.	7.	12.	0.	4.	40.	6549.
4.00	125.	55.	61.	3.	27.	270.	22002.
6.00	404.	185.	156.	11.	83.	839.	45590.
8.00	932.	439.	306.	26.	187.	1891.	77027.
10.00	1783.	857.	519.	51.	353.	3564.	116136.
12.00	3030.	1481.	801.	89.	594.	5995.	162794.
14.00	4746.	2351.	1157.	141.	923.	9319.	216908.
16.00	7000.	3510.	1594.	210.	1355.	13670.	278404.
18.00	9864.	5059.	2122.	300.	1908.	19253.	348551.

ASSET/MONOLA VERSION 1.0 - PROPELLER MODULE - 3/18/93 14.45.33.

PRINTED REPORT NO. 1 - SUMMARY

ENDUR CONFIG IND   NO TS
PROP TYPE IND   FP   PROP SERIES IND   TROOST
PROP DIA IND   CALC   PROP LOC IND   GIVEN
PROP AREA IND   CALC   PROP ID IND
SHAFT SUPPORT TYPE IND   RUDDER TYPE IND

MAX SPEED, KT   16.25   ENDUR SPEED, KT   15.00
MAX EHP (/SHAFT), HP   7142.   ENDUR EHP (/SHAFT), HP   5679.
MAX SHP (/SHAFT), HP   11306.   ENDUR SHP (/SHAFT), HP   9005.
MAX PROP RPM   170.0   ENDUR PROP RPM   157.4
MAX PROP EFF   0.632   ENDUR PROP EFF   0.631

SUSTN SPEED, KT   15.00   PROP DIA, FT   14.78
SUSTN EHP (/SHAFT), HP   5679.   NO BLADES   5.
SUSTN SHP (/SHAFT), HP   9005.   PITCH RATIO   0.95
SUSTN PROP RPM   157.4   EXPAND AREA RATIO   0.549
SUSTN PROP EFF   0.631   CAVITATION NO   4.30

NO PROP SHAFTS   2.0

TOTAL PROPELLER WT, LTON   15.57

PRINTED REPORT NO. 2 - PROPELLER CHARACTERISTICS

PROP ID IND
NO PROP SHAFTS   2.
PROP DIA, FT   14.78
NO BLADES   5.
PITCH RATIO   0.95
EXPAND AREA RATIO   0.549
THRUST DED COEF   0.000
TAYLOR WAKE FRAC   0.000
HULL EFFICIENCY   1.000
REL ROTATE EFF   1.000

| | ——— CONDITIONS ——— | | |
CHARACTERISTICS	MAXIMUM	SUSTAINED	ENDURANCE
SPEED, KT	16.25	15.00	15.00
RPM	170.0	157.4	157.4
THRUST/SHAFT, LBF	143253.	123370.	123370.
EHP/SHAFT, HP	7142.	5679.	5679.
TORQUE/SHAFT, FT-LBF	349330.	300540.	300540.
SHP/SHAFT, HP	11306.	9005.	9005.
ADVANCE COEF (J)	0.655	0.653	0.653
THRUST COEF (KT)	0.188	0.189	0.189
TORQUE COEF (10KQ)	0.310	0.311	0.311
OPEN WATER EFFY	0.632	0.631	0.631
PC	0.632	0.631	0.631

PRINTED REPORT NO. 11 - ELECTRIC LOADS

LOADS	WINTER CRUISE KW	WINTER BATTLE KW	SUMMER CRUISE KW
PROPULSION AND STEERING	199.1	231.0	129.4
LIGHTING	1178.1	1154.5	1178.1
MISCELLANEOUS ELECTRIC	46.1	40.1	46.1
HEATING	7632.8	3892.7	381.6
VENTILATION	1450.2	1116.7	1450.2
AIR CONDITIONING	2620.5	2463.3	3911.2
AUXILIARY BOILER AND FRESH WATER	435.2	322.1	435.2
FIREMAIN	573.8	809.1	573.8
UNREP AND HANDLING	105.5	25.3	105.5
MISC AUXILIARY MACHINERY	101.9	57.0	101.9
SERVICES AND WORK SPACES	162.1	53.5	162.1
SUBTOTAL	14505.3	10165.3	8475.2
TOTAL	14505.3	10165.3	8475.2
TOTAL (INCLUDING MARGINS)	14505.3	10165.3	8475.2

MAX MARG ELECT LOAD	14505.3
24 HR AVG ELECT LOAD	6388.7
CONNECTED ELECT LOAD	38439.0
ANCHOR ELECT LOAD	11169.1
VITAL ELECT LOAD	4391.0
EMERGENCY ELECT LOAD	3917.3
MAX STBY ELECT LOAD	11169.1

Since it was desired to work with the total connected load and not the operating loads, the following procedure was used to estimate the total connected load.

1. The worst case load in each category estimated by ASSET was taken as the starting point. Since the worst case heating load was higher than the worst air conditioning load, the air conditioning load was ignored for this analysis.

2. The loads in each category were changed based on the basis of the estimate as discussed above to determine the actual maximum operating load.

3. The loads in each category were multiplied by 2.65 as an estimate of the total connected load in that category.

4. The total connected loads in each category were then increased by 10% for growth margin.

The above procedure is considered both reasonable and conservative given the nature of the HL(X). The results are summarized in Table 1.

Table 1. HL(X) Ships Service Load Estimation (All Loads in kW)

Load	ASSET Estimation	Basis	HL(X) Maximum Operating	HL(X) Maximum Connected	HL(X) Max Connected with Margin
Lighting	1,178	Volume	393	1,041	1,146
Heating	7,633	Volume	2,544	6,742	7,416
Ventilation	1,450	Volume	483	1,280	1,408
Fresh Water	435	# Personnel	435	1,153	1,268
Firemain	809	Unchanged	809	2,144	2,358
Handling	106	Unchanged	106	281	309
Services	162	Personnel	162	429	472
Total	11,773		4,932	13,070	14,377